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EFFECT OF FERTILIZERS ON THE GERMINATION OF SEEDS[1]

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It is becoming an increasingly widespread practice in some sections for farmers to mix the seeds of grasses and clovers with fertilizers and to sow the seed and fertilizers together. The question is frequently asked whether the seed will be injured if they are not sown immediately after they are mixed with the fertilizer. The investigation reported in this paper was started to answer this question.

MATERIALS AND METHODS

The seeds used were alsike clover, Canada bluegrass, creeping bent grass, crimson clover, Kentucky bluegrass, lespedeza, meadow fescue, orchard grass, redtop, red clover, sapling clover, sheep's fescue, tall meadow oat grass, timothy, white clover, white sweet clover. All the different kinds of seeds showed good germination between moist blotting paper in the laboratory. Two hundred seeds of each kind were placed in contact with various fertilizers for one-week, two-week, three-week, and four-week periods. The fertilizers used were acid phosphate (16 per cent P_2O_5), ammonium chloride, ammonium nitrate, ammonium phosphate, ammonium sulfate, calcined phosphate, calcium carbonate, calcium cyanamide, calcium oxide, potassium chloride, potassium sulfate, and synthetic urea. The seeds were planted in Hagerstown silt loam in the greenhouse. The soil was held as far as practicable at optimum moisture conditions. The rates of application of the fertilizers are shown in table 1.

RESULTS

Germination as affected by fertilizers

As shown by the data in table 2 calcium cyanamide was most injurious to germination. However, all of the fertilizers reduced germination to some extent. In some instances urea reduced germination to a marked degree.

The different kinds of seeds were affected in different degrees by the fertilizers. Meadow fescue, with the exceptions of calcium cyanamide and calcium carbonate treatments, germinated higher when in contact with fertilizers than when seeded without being in contact with fertilizers. Timothy seed

[1] Abstract from minor thesis in agronomy submitted in partial fulfillment of the requirements for the degree of Master of Science.

apparently was injured but little by being seeded in contact with different fertilizers, except calcium cyanamide. Kentucky bluegrass, and white sweet clover seeds were injured more by the fertilizers than the other seeds used, as shown in table 3.

The average percentage germination of grass seeds under all treatments for all the periods was 70, as compared with 100 for the checks, and with 62 to 100 for the other kinds of seeds. In other words, there was practically no difference in the reduction in germination of seeds of grasses and those of the other kinds used.

Effect of time of contact of seed with fertilizer on the germination

The results shown in tables 2 and 3 indicate that the injury to germination is not affected by the seeds being in contact with the fertilizers different lengths

TABLE 1

Rates of applying fertilizers per acre

FERTILIZER	AMOUNTS
	pounds
Acid phosphate	200
Ammonium chloride	100
Ammonium nitrate	100
Ammonium phosphate	100
Ammonium sulfate	100
Calcined phosphate	200
Calcium carbonate	500
Calcium cyanamide	100
Calcium oxide	250
Potassium chloride	100
Potassium sulfate	100
Urea	50

of time before being sown. There are no consistent differences between the effects on germination with the seeds remaining in contact with the fertilizers for 1, 2, 3, or 4 weeks. The length of time seeds are in contact with dry fertilizers is inconsequential.

The data in table 2 do not show whether the injury occurred before or after the seeds were planted. In order to study this point further, the seeds of crimson clover and tall meadow oat grass were placed in contact with the fertilizers for 4 weeks. Some of the seeds were then separated from the fertilizers and seeded and some were left in contact with the fertilizers and seeded. The results as shown in table 4 indicate that all the injury was produced after the seeds were planted and that the contact of the seeds with the dry fertilizers for the 4-week period did not injure the germination.

The ability of the soil to counteract the injurious effects of fertilizers on germination of crimson clover was determined by applying the fertilizers in

TABLE 2

Percentage of germination of clovers and grasses when placed in contact with different fertilizers for varying periods of time and then placed in the soil with the fertilizers

Seeds	Lespedeza				White clover				Kentucky bluegrass				Canada bluegrass				Meadow fescue			
Germination	*per cent*				*per cent*				*per cent*				*per cent*				*per cent*			
Weeks of contact	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Treatment																				
Check	70	60	59	53	42	37	66	52	22	18	28	24	20	44	36	34	20	29	28	26
Ammonium sulfate	54	44	57	57	16	29	29	58	14	14	12	8	28	8	10	26	30	33	29	27
Acid phosphate	61	48	67	51	55	38	33	47	8	8	4	4	14	14	22	14	28	29	42	34
Calcium oxide	42	34	57	21	24	32	24	24	8	8	8	10	18	16	8	20	27	26	16	31
Ammonium chloride	21	36	30	35	33	31	29	59	6	6	14	6	18	6	4	28	25	28	30	26
Check	68	82	83	58	50	33	59	55	22	28	24	20	24	20	36	30	22	26	22	22
Calcined phosphate	56	36	45	54	23	31	66	40	16	22	20	10	20	26	28	30	26	30	30	23
Potassium sulfate	26	56	62	38	16	34	50	26	2	4	8	6	20	22	28	18	29	33	30	30
Ammonium nitrate	23	40	45	32	19	16	48	32	8	20	12	6	14	16	10	22	27	32	25	22
Potassium chloride	28	34	51	38	26	28	35	28	9	16	4	6	8	10	12	12	29	32	36	28
Ammonium phosphate	46	47	47	58	4	9	27	28	8	6	6	6	8	12	12	24	22	36	27	34
Check	50	72	71	59	44	54	59	41	18	24	14	20	42	28	18	16	17	22	29	27
Urea	52	62	50	62	18	10	29	23	9	10	4	8	10	20	22	10	24	18	22	27
Calcium cyanamide	8	5	6	14	10	2	11	7	2	0	0	2	0	2	0	0	0	0	0	0
Calcium carbonate	62	48	61	40	30	24	55	42	26	26	34	16	30	32	22	32	27	19	20	14

Seeds	Sheep's fescue				Red clover				Alsike clover				Sapling clover				Crimson clover				White sweet clover			
Germination	*per cent*				*per cent*				*per cent*				*per cent*				*per cent*				*per cent*			
Weeks of contact	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Treatment																								
Check	18	18	20	18	38	39	42	45	61	50	48	45	35	41	35	38	29	23	20	21	24	22	20	19
Ammonium sulfate	20	24	28	17	23	51	42	50	44	35	22	47	17	18	18	10	12	17	18	11	15	6	5	8
Acid phosphate	14	11	6	3	30	24	24	50	39	53	27	61	28	39	31	28	21	15	16	9	15	14	12	14
Calcium oxide	27	19	31	20	28	35	31	25	32	43	42	31	35	32	49	43	14	12	14	13	20	14	16	19
Ammonium chloride	23	12	12	14	34	22	22	20	35	49	28	45	14	11	7	4	18	15	6	18	9	6	6	7
Check	22	27	19	21	50	55	60	61	59	65	67	60	33	45	56	49	28	25	21	17	23	22	14	24
Calcined phosphate	15	8	23	29	54	42	54	55	54	54	56	55	41	36	36	40	27	22	21	14	22	21	12	10
Potassium sulfate	22	20	20	13	64	33	50	59	45	58	61	60	30	26	26	14	26	16	15	14	18	15	9	7
Ammonium nitrate	15	18	17	12	42	29	22	39	55	60	52	28	14	22	11	4	14	15	21	13	7	6	5	4
Potassium chloride	24	25	25	18	48	33	42	53	45	40	54	54	28	25	20	16	48	28	29	32	20	12	9	10
Ammonium phosphate	25	21	14	6	28	20	27	25	18	38	38	37	12	19	12	8	22	8	9	12	5	7	5	3
Check	19	22	20	19	65	63	66	59	51	52	69	61	40	36	47	42	31	20	19	18	25	20	18	21
Urea	25	19	9	11	8	10	6	10	10	14	25	16	19	27	18	13	14	8	5	12	5	4	3	2
Calcium cyanamide	0	0	0	0	3	3	1	2	5	6	4	7	3	2	2	2	4	1	2	2	3	2	4	2
Calcium carbonate	20	33	31	20	51	61	50	61	67	59	48	39	42	36	53	34	28	14	27	14	20	19	19	18

TABLE 2—*Continued*

Seeds	Tall meadow oat grass				Rhode Island bent grass				Orchard grass				Creeping bent grass				Timothy			
Germination	*per cent*				*per cent*				*per cent*				*per cent*				*per cent*			
Weeks of contact	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Treatment																				
Check	52	43	36	43	12	9	10	14	20	32	22	28	38	42	29	51	92	90	86	88
Ammonium sulfate	50	49	49	43	3	11	8	7	8	16	8	6	23	36	31	34	81	74	74	72
Acid phosphate	49	51	34	38	8	9	11	12	16	20	20	18	14	38	30	39	84	90	86	84
Calcium oxide	37	35	44	41	2	0	3	4	24	16	24	24	31	30	40	34	74	72	70	67
Ammonium chloride	40	32	44	35	7	9	9	8	24	10	16	22	18	33	34	36	58	74	74	70
Check	44	44	49	44	9	17	11	14	24	22	28	30	50	44	56	46	84	83	88	84
Calcined phosphate	36	33	33	31	4	6	5	6	28	28	24	36	34	48	33	55	91	90	90	86
Potassium sulfate	38	40	34	31	3	7	9	6	10	20	16	18	30	25	43	32	36	78	71	82
Ammonium nitrate	46	66	37	36	7	6	8	5	22	18	22	18	10	22	28	34	26	70	72	56
Potassium chloride	45	39	51	40	10	8	10	12	14	18	22	10	13	21	31	51	38	80	82	70
Ammonium phosphate	45	42	56	42	7	8	11	9	24	24	16	14	8	18	14	24	48	82	68	72
Check	48	46	38	46	9	17	8	14	24	22	24	30	38	54	68	60	86	90	82	80
Urea	26	27	33	22	11	14	9	5	14	12	6	4	8	9	23	9	77	44	52	44
Calcium cyanamide	0	0	1	3	2	0	1	0	4	2	6	4	2	0	3	0	1	0	2	2
Calcium carbonate	45	39	35	30	4	7	9	8	18	16	20	18	49	52	62	64	88	91	90	91

the row and allowing a 5-day period to elapse before sowing the seed. The results presented in table 4 indicate that by applying fertilizers several days before sowing the seeds, the harmful effects of fertilizers on germination can be largely overcome.

Nature of the injury to the germination of seeds by fertilizers

The question frequently arises whether the injury resulting from applying fertilizers in contact with seeds takes place before or after the radicles or plumules emerge from the seed coats. Sherwin (2) found that germination was inhibited by inorganic fertilizers and the seedlings injured by organic fertilizers while Hicks (1) and Shive (3), using inorganic fertilizers, found that injury occurred to the seedling.

The seeds of crimson clover and timothy were planted in contact with 500 mgm. of various fertilizers in 50 gm. of sand in Petri dishes and the sand was held at 50 per cent of its saturation. The fertilizers used were ammonium sulfate, calcium cyanamide, potassium sulfate, and urea.

The seeds were left in the sand for 10 days. Some of them swelled, but no germination took place. The harmful effects of the fertilizers in these cases evidently were due to the injury to the seed before germination rather than to the seedling.

From the experiments conducted to study the effect of solutions of the fertilizer salts of different concentrations on the plasmolysis of the seedlings and the

TABLE 3

Percentage of germination of clovers and grasses when placed in contact with different fertilizers for varying periods of time and then placed in the soil with the fertilizers

Average for all treatments

SEEDS	TREATMENT	GERMINATION OF SEED TREATED				GERMINATION FOR ALL PERIODS OF CONTACT AS COMPARED WITH CHECK
		1 week	2 weeks	3 weeks	4 weeks	
		per cent	*per cent*	*per cent*	*per cent*	*per cent*
Red clover	Fertilizer	34	30	32	37	62
	Check	51	52	56	55	100
Alsike clover	Fertilizer	37	42	38	40	70
	Check	57	56	55	55	100
Sapling clover	Fertilizer	28	24	24	18	57
	Check	36	41	46	43	100
Crimson clover	Fertilizer	21	14	15	14	70
	Check	29	23	20	19	100
White sweet clover	Fertilizer	13	11	9	9	51
	Check	24	21	17	21	100
Lespedeza	Fertilizer	40	41	48	42	65
	Check	63	71	71	57	100
White clover	Fertilizer	23	26	36	34	61
	Check	45	41	61	49	100
Kentucky bluegrass	Fertilizer	10	12	11	7	46
	Check	21	23	22	21	100
Canada bluegrass	Fertilizer	16	15	15	20	56
	Check	29	31	30	27	100
Meadow fescue	Fertilizer	24	26	26	25	104
	Check	20	26	26	25	100
Sheep's fescue	Fertilizer	19	17	17	13	81
	Check	20	22	20	19	100
Tall meadow oat grass	Fertilizer	38	38	38	33	84
	Check	48	43	41	44	100
Rhode Island bent grass	Fertilizer	6	7	8	7	58
	Check	10	14	10	14	100
Orchard grass	Fertilizer	17	17	17	16	66
	Check	23	25	25	29	100

TABLE 3—*Continued*

SEEDS	TREATMENT	GERMINATION OF SEED TREATED				GERMINATION FOR ALL PERIODS OF CONTACT AS COMPARED WITH CHECK
		1 week	2 weeks	3 weeks	4 weeks	
		per cent	*per cent*	*per cent*	*per cent*	*per cent*
Creeping bent grass	Fertilizer	20	28	31	34	59
	Check	42	47	51	52	100
Timothy	Fertilizer	58	70	69	67	77
	Check	87	88	85	84	100

TABLE 4

Percentage of germination of seeds sown with and without fertilizers

SEEDS	Crimson clover			Tall meadow oat grass	
Method of seeding	Separately	In contact	After 5 days	Separately	In contact
Germination	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Treatment					
Acid phosphate	54	9	24	41	38
Ammonium chloride	46	18	12	33	35
Ammonium nitrate	68	13	20	30	36
Ammonium phosphate	71	12	28	47	42
Ammonium sulfate	66	11	43	42	43
Calcined phosphate	61	14	50	26	31
Calcium carbonate	64	14	45	35	30
Calcium cyanamide	65	2	17	18	3
Calcium oxide	63	13	31	30	41
Potassium chloride	57	32	56	23	40
Potassium sulfate	49	14	58	47	31
Urea	65	12	14	35	22
Check	44	44	44	23	23

germination of the seeds, it seems that the concentration which allows seeds to germinate will not materially injure the seedlings.

SUMMARY

Under the conditions of this experiment and with the fertilizers and seeds used the following statements seem warranted:

1. The mixing of seeds and dry fertilizers together for one to four weeks does not injure the seeds to any noticeable extent.
2. The injury to germination, which occurs, takes place after the seeds are placed in moist soil and not before seeding.
3. Some fertilizers cause greater reduction in germination than others.
4. Some seeds show greater reduction in germination than others because of contact with fertilizers in the soil.

5. The injury from the fertilizers seems to be to the seed, preventing germination rather than destroying the seedling before it appears above the surface of the soil.

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THE HYDROMETER AS A NEW METHOD FOR THE MECHANICAL ANALYSIS OF SOILS

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The physical and, to a large extent, also the chemical characteristics of a soil, are controlled chiefly by the proportion of its particles of various sizes. Such physical and chemical properties or relationships of a soil as structure and tilth, ease of cultural operations, water-holding capacity, water-percolating capacity, capillary movement of water, evaporation of water, availability of water, wilting coefficient, heat of wetting, adsorbability and retainability of plant-food constituents, reactivity toward chemical reagents, solubility, and productivity, are all influenced largely by the size of particles present in the soil. This fundamental fact has long been recognized and has led to a tremendous amount of work on the part of various investigators in an effort to devise methods for making mechanical analyses of soils and determining the proportion of their particles of various sizes. The old standard mechanical analyses for this purpose are well known and need not be considered here. These methods, however, while giving an approximate determination of the amount of the various soil particles, are very laborious and time consuming. The desire to have a simpler, quicker and more accurate method for the determination of the physical constituents of the soil, has led many investigators, in the last few years, to undertake a study of the subject. Different methods for the purpose have been proposed. Among these recent methods may be mentioned those of Oden (5), Robinson (6), Jennings, Thomas, and Gardner (2), Johnson (3), and Keen (4).

The method of Oden is probably the most ingenious. It consists in placing the pan of a balance at the bottom of a column of soil suspensions, allowing the soil particles to settle upon this pan, and recording automatically the time required for a definite weight to settle. From an accumulation curve that is thus obtained, the size distribution of the mineral particles of soils is calculated by the application of certain mathematical formulas.

This original method of Oden has been somewhat modified by Keen, Johnson, and others.

[1] At the author's request, the priority rights of this paper were transferred to "The hydrometer as a new and rapid method for determining the colloidal content of soils," which was received for publication July 23, 1926 and which appeared in *Soil Science* 23: 319-335.

Robinson's method consists of allowing to settle in a cylindrical vessel a soil suspension of known concentration, which is then sampled with a 20-cc. pipette at different times and the dry matter determined. By this method it is claimed that the mechanical composition of a soil or clay can be derived from the determination of the concentration of the settling suspension for different values of depth time.

The method of Jennings, Thomas and Gardner, is about the same as that of Robinson with the main exception that in the former a "multiple-mouthed pipette" is employed, which would tend to make the process of sampling more accurate.

HYDROMETER METHOD

While investigations to devise methods (1) for the determination of the colloidal material in soils were being conducted, the idea occurred, that the hydrometer might be advantageously employed to estimate the colloidal, or at least the finer material in the soil, and also to measure the rate of settling of the soil particles and thus obtain a distribution curve from which the size distribution of the soil particles might be calculated.

The method was examined and from the results obtained, gives great promise for its successful application in estimating the fine material in the soil and especially in obtaining the distribution curve.

The hydrometer employed was a Zuevenne's Lactodensimeter[2] (plate 1) of a very large volume surface and considerable weight, both of which made it very sensitive and accurate. This particular Lactodensimeter had in its stem a thermometer, the graduations on which were used as points for comparative measurement of the density of the suspension of the different soils, or of the same soil at different periods of settling. The thermometer was graduated to 1 degree and the readings could be estimated to about 0.2 degrees. This degree of division on the scale seemed to give all the accuracy desired for practical purposes. The divisions ranged from 30 to 115 and consequently the density of wide degrees of concentration of soil suspensions could be measured.

The hydrometer was calibrated so that the density could be read directly on its divisions, by determining the reading of suspensions of various concentrations, then evaporating these suspensions down to dryness to ascertain the amount of dry material present, and then applying the necessary calculations to ascertain the amount of dry material to which each division of the hydrometer is equal per unit volume of water. The calibrations were done in very concentrated and very dilute suspensions of very colloidal clays. These extreme calibrations showed that each division on the hydrometer was equivalent to 0.849 gm. per 1000 cc. of water. Each reading on the hydrometer, therefore, could be translated directly into grams per liter of water.

The actual determinations were made by placing 75 gm. of soil in a large earthenware mortar. The soil was then washed two or three times with dis-

[2] Since this paper was written a new soil hydrometer has been made and a new method has been adopted for dispersing soils.

tilled water by decantation, care being taken to prevent stirring up the soil. The purpose of this washing is to eliminate the salts, and thus facilitate the deflocculation and make the soils more comparable. After the soils were washed they were gently rubbed with a pestle to break up the compound soil particles and to put the soil into the dispersed condition. The soil was then mixed with an excess of water, allowed to stand for a few seconds, and the supernatent liquid poured into a cylinder. The latter had a capacity of 1100 cc. and was 17½ inches high and 2½ inches in diameter. The process of rubbing, mixing with water, and decanting was continued until all the soil material in clays, or all the dispersable material, in sandy soils was disperesd. The cylinder containing the suspension was then filled with distilled water up to a certain point, shaken vigorously for about 5 minutes, and then set upon a table. The hydrometer was quickly placed in the suspension and readings were taken every minute for any length of time desired. Some times the readings were extended to several hours, but it was found that after the first hour the rate of settling is very slow.

Various quantities of soils were employed, but only the results with 75 gm. will be presented here. With this quantity of soil was used in every case 1075 cc. of water. In the calculation of the results, however, only 1000 cc. are employed, the other 75 cc. are considered to be consumed in wetting or saturating the soil.

The experiments were carried on at room temperature. The room temperature remained quite constant, and the thermometer in the hydrometer showed that the temperature of the suspension would not change much during the experiment.

Repeated trials showed that the results could be duplicated very closely or exactly, if the soil was well dispersed and if the temperature remained the same.

It was observed that the hydrometer would make small sudden jumps occasionally, as the mercury column of a thermometer does. This is probably due to a lag in the movement of the hydrometer. The irregularities thus produced, however, are so insignificant that they are hardly noticeable when the results are plotted.

It was also noticed that at the top of the hydrometer bulb or shoulder a small amount of sediment would settle. This occurred, however, only occasionally and on long standing and the amount was usually so small that it could hardly affect the results.

As is well known of course, the density of the suspension in a column of liquid varies with the depth, being greatest at the bottom of the column and smallest at the top of the column. The hydrometer reading proved to give an average of all the different densities in the column from top to bottom. Soil particles continue to influence the density and hence, the hydrometer reading, as long as they are dispersed in the liquid, but cease to exert an influence as soon as they settle out of the liquid.

The method as a whole is very simple, quick and accurate, and appears to have considerable promise. It can certainly give very good results on the rate of settling, from which the distribution curve of various sizes of particles can be worked out. It also gives promise of being able to determine, at least in an approximate way, the fine material in the soil, and possibly also the colloidal content.

TABLE 1

Rate of settling of soils as measured by the hydrometer method

Figures represent amount of dry material per liter of water staying in suspension at any given time out of 75 gm. sample taken.

TIME	OHIO SILT LOAM	TENNESSEE SILT LOAM	URBANA CLAY LOAM	CALIFORNIA YOLO CLAY LOAM	CALIFORNIA YOLO CLAY	ONTONAGON SILT LOAM A_1	ONTONAGON SILT LOAM A_2	ONTONAGON SILT LOAM B_1
minutes	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
0	63.053	44.375	63.053	67.289	62.204	62.204	64.751	66.449
1	52.865	41.828	58.808	60.506	57.110	57.959	58.808	63.902
2	46.073	40.300	52.865	54.563	52.865	55.412	56.261	62.204
3	42.677	38.008	49.469	50.318	50.318	53.714	54.139	61.779
4	38.432	36.055	46.073	46.922	47.347	52.865	52.865	61.355
5	36.734	34.187	43.526	45.649	46.073	51.167	51.595	61.100
6	34.187	32.574	40.979	43.526	44.800	50.318	51.167	60.506
7	32.065	30.961	39.281	41.828	54.102	49.469	50.743	60.336
8	30.791	29.518	36.734	40.555	41.828	48.620	50.063	59.826
9	29.518	28.244	35.461	39.281	40.555	47.771	49.469	59.572
10	28.074	26.546	34.187	38.008	39.451	47.347	48.875	59.402
11	26.291	25.357	32.914	36.904	38.602	46.752	48.620	58.977
12	25.273	24.678	31.640	36.564	37.753	46.243	48.196	58.638
13	23.999	23.744	30.367	35.885	36.904	45.733	47.686	58.383
14	23.150	22.726	29.518	35.036	36.310	45.394	47.092	58.128
15	22.471	22.131	28.669	34.442	35.800	45.054	46.752	57.959
16	21.877	21.452	27.820	33.763	35.036	44.630	46.243	57.789
17	21.282	20.773	26.471	32.914	34.612	44.375	46.073	57.619
18	20.003	20.433	26.122	32.489	34.187	44.205	45.818	57.534
19	19.924	19.584	25.273	31.895	33.763	43.696	45.563	57.279
20	19.584	18.990	24.848	31.470	32.914	43.441	45.394	57.194
30	16.188	14.915	20.263	27.225	28.669	40.979	44.120	56.006
60	11.159	10.160	13.896	21.367	22.216	37.753	41.828	53.459
75	10.120		12.113					
95			10.415	17.200	18.900	35.885		
240	7.014				12.113		34.612	
1260								33.763

In view of the foregoing description and discussion it would appear that the hydrometer method would have many advantages over the other methods that have been proposed. In the first place, it is simpler, much quicker, more practical and ought to be more accurate than most of the other methods, especially those of Robinson and Jennings, Thomas, and Gardner, where the suspensions have to be sampled by pipettes. The fact that the density of the

suspension column varies with the depth, that the hydrometer reading gives an average of all the densities from the top to the line where soil particles go out of suspension and settle, and also that the hydrometer reading indicates directly the amount of material that is in suspension at any particular moment, makes the method very unique indeed. Furthermore, the whole soil can be used.

TABLE 2

Rate of settling of soils as measured by the hydrometer method

Figures represent amount of dry matter per liter of water staying in suspension at any given time, out of 75 gm. sample taken.

TIME	STEWART LOAM A_1	STEWART LOAM A_2	STEWART LOAM B_1	ONAWAY LOAM A_1	ONAWAY LOAM A_2	ONAWAY LOAM C_1	NAPANEE SILT LOAM A_1	NAPANEE SILT LOAM B_1	NAPANEE SILT LOAM C_1
minutes	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
0	35.036	38.432	37.583	20.603	22.301	30.791	58.808	58.808	59.657
1	27.820	26.122	26.122	11.689	14.660	26.122	49.045	51.107	52.865
2	21.452	23.150	22.726	8.712	12.962	23.999	44.800	47.347	49.469
3	19.754	21.452	19.754	7.430	12.113	23.000	40.979	44.969	46.498
4	19.216	20.603	19.075	7.014	11.360	22.301	38.602	42.677	44.375
5	17.207	19.499	18.056		10.840	21.612	36.564	41.149	42.847
6	16.438	18.481	16.952		9.910		35.036	39.026	41.658
7	15.509	18.056	16.188		9.620		33.338	38.602	40.130
8	15.085	17.377	15.509		9.400		31.810	37.583	38.941
9	14.236	17.037	15.085		9.050		30.791	36.734	38.008
10	13.811	16.443	14.660		8.792	15.589	29.687	36.065	37.074
11	13.407	16.103	14.405		8.712		28.753	35.206	36.310
12	13.142	15.679	14.066		8.552		27.989	34.866	35.885
13	12.698	15.424	13.811		8.288		27.395	34.187	35.206
14	12.273	15.169	13.556		8.128		26.376	33.847	34.527
15	11.033	15.000	13.301		7.863		25.867	33.338	34.017
16					7.703		25.188	32.489	33.338
17					7.519		24.848	32.234	32.659
18					7.279		24.169	31.810	32.319
19					7.094	13.202	23.744	31.385	32.065
20	10.335	13.387	12.368		7.014		23.320	30.961	31.470
30	8.208	12.113	11.179				19.584	27.310	26.122
60			8.882			7.359	14.236	23.575	10.415

This work is presented as a preliminary report. Being of a preliminary nature the data have not been subjected to mathematical treatment. This will be done subsequently when the data have been checked in various ways. The distribution curve as actually obtained by the experimental data is shown, however.

EXPERIMENTAL DATA

In accordance with the hydrometer method described, the rate of settling was determined for over 30 soils ranging from sand to the heaviest type of clay.

The specific soils investigated included Hillsdale sandy loam A_1, B_1 and B_2 horizons; Chippewa fine sandy loam A_1, B_1 and B_2; Fox loam A_2, B_1 and B_2; Stewart loam A_1, A_2 and B_1; Onway loam A_1, A_2, B_1 and C_1; Napanee silt loam A_1, B_1 and C_1; Ohio silt loam; Tennessee silt loam; Michigan silt loam; Illinois clay loam; California Yolo clay loam and clay; Ontonagon silt loam A_1, A_2, and Ontonagon clay B_1. The results obtained on these various soils are presented in tables 1, 2 and 3. Because of lack of space, not all of the readings are given

TABLE 3

Rate of settling of soils as measured by the hydrometer method

Figures represent amount of dry material per liter of water, staying in suspension at any given time out of 75 gm. sample taken.

TIME	HILLSDALE SANDY LOAM A_1	HILLSDALE SANDY LOAM B_1	HILLSDALE SANDY LOAM B_2	CHIPPEWA FINE SANDY LOAM A_1	CHIPPEWA FINE SANDY LOAM B_2	FOX LOAM A_2	FOX LOAM B_1	FOX LOAM B_2
minutes	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
0	25.697	20.603	21.452	49.469	49.469	28.244	30.791	17.632
1	18.481	15.509	12.113	21.877	11.26	22.726	23.999	15.085
2	16.358	14.236	10.415	15.934	4.00	19.754	21.282	13.811
3	15.085	13.387	9.137	13.387		18.056	19.584	12.962
4	13.811	12.538	7.700	11.689		16.358	18.056	11.858
5	13.132	11.689	7.439	10.400		15.509	17.037	10.585
6	12.538	11.264	7.014	9.500		14.660	15.934	8.712
7	11.773	10.840		9.100		13.811	14.830	7.014
8	11.349	10.245		8.712		12.962	13.217	
9	11.179	9.561		8.270		12.113	12.538	
10	10.585	9.137		7.014		11.264	11.264	
11	10.160	8.712				10.585	9.991	
12	9.736	8.288				10.415	8.882	
13	9.476	7.863				9.821	7.863	
14	9.137	7.863				9.137	7.014	
15	8.797	7.693				8.982		
16	8.627	7.184						
17	8.372	7.014						
18	8.203							
19	8.033							
20	7.863							
21	7.693							
22	7.439							

for some of the soils whose rate of settling was measured for many hours. To facilitate presentation, the typical data of several of the soils are graphed and shown in plate 2.

The data in tables 1, 2, and 3 together with plate 2 show unmistakably that the hydrometer can be used to measure the rate of settling of soils from which a distribution curve might be worked out. It will be seen both from the tables and from the figure that the results are regular and consistent and

that they must follow certain physical laws. The data plot into unusually smooth curves which would strongly indicate the applicability and reliability of the method.

An examination of the results more in detail shows that the rate at which the soil particles settle varies tremendously with the different soils. In some soils the rate is exceedingly rapid, in others it is very slow. In Chippewa loam, for instance, the settling is so rapid that at the end of 2 minutes there is only about 4 gm. in suspension in a liter of water out of 75 gm. of the original sample. In Ontonagon Clay B_1 at the end of 2 minutes there is 62.204 gm. in suspension out of the 75 gm., and even at the end of 21 hours there is still 33.763 gm. in suspension. As would be expected, of course, the greater the colloidal content of a soil the slower is the rate of settling and the greater the amount of material in suspension at any given time. The converse of this would also be true There are of course some factors which sometimes tend to modify these rules.

As stated previously, no attempt will be made at this time to apply Stokes' law and other mathematical formulae to these experimental results in order to obtain the distribution curve, i.e. the sizes and the amount of the various soil particles. This will be reserved for a later date.

It is of interest to state here that there seems to be a relationship between the colloidal content of a soil as determined by the heat of wetting method and the amount of material remaining in suspension after standing a given time. This suggests the possibility that the hydrometer method might also be used to estimate the fine or colloidal material in soils.

SUMMARY

The hydrometer method is presented as a new means of measuring the rate of settling of soil particles and thus of obtaining a curve from which the distribution of the soil particles of various sizes might be calculated.

The method also gives promise of allowing an estimation of the amount of fine or colloidal material in soils.

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PLATE 1

TYPE OF HYDROMETER, CYLINDER, AND MORTAR EMPLOYED

HYDROMETER FOR MECHANICAL ANALYSIS OF SOIL

GEORGE JOHN BOUYOUCOS

PLATE 1

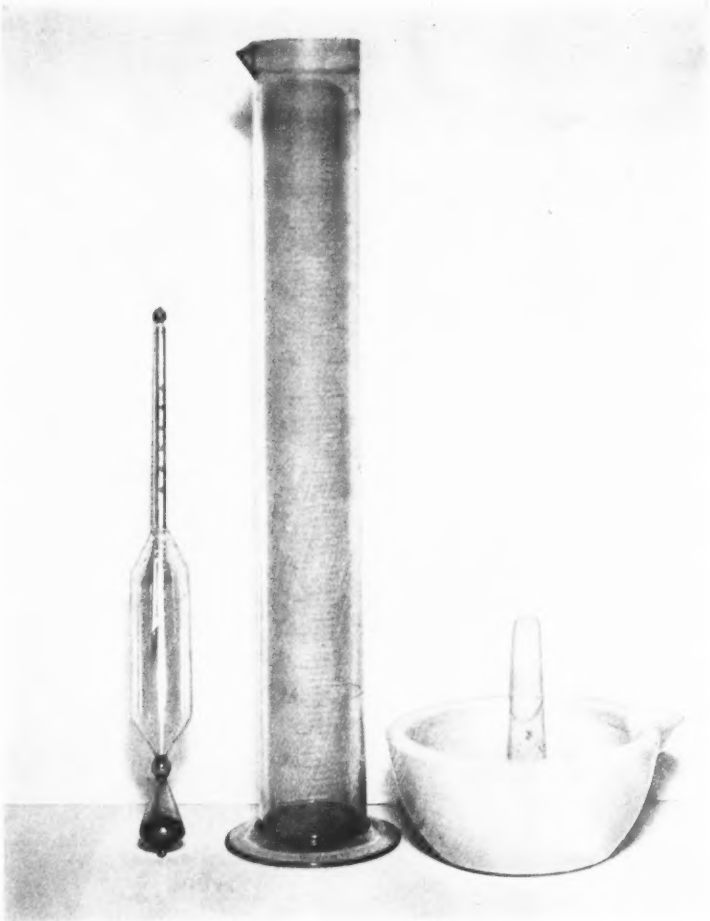
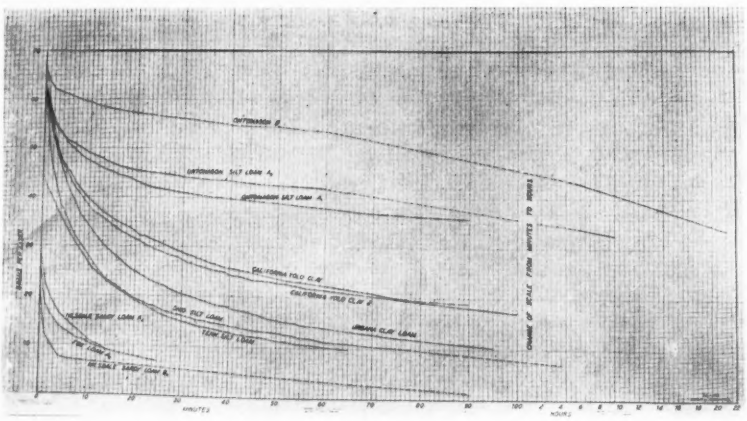


PLATE 2

CURVES SHOWING RATE OF SETTLING OF SOIL PARTICLES AS MEASURED BY HYDROMETER


CUTTOMWOOD B
CUTTOMWOOD SILT LOAM A2
CUTTOMWOOD SILT LOAM A1
CALHOUN RED CLAY B
CALHOUN RED CLAY A
URBANA CLAY LOAM
TAMA SILT LOAM
MINUTES
HOURS

EFFECT OF MOISTURE, TEMPERATURE, AND OTHER CLIMATIC CONDITIONS ON R. LEGUMINOSARUM IN THE SOIL[1]

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The longevity of the nodule bacteria in the soil in the absence of the host plant is still largely a matter of speculation. The earlier belief that these organisms are extremely sensitive to sunlight and desiccation is no longer acceptable, for more recent work has demonstrated that under certain conditions they are able to survive relatively wide extremes in temperature and long periods of exposure to sunlight or desiccation. The chief factors influencing the longevity of these bacteria in the soil are conceded to be the physical condition, composition, and reaction of the soil; the extremes in the temperatures of summer and winter; and the extremes in the soil moisture of the dry and wet seasons. The factors of temperature and moisture are especially significant in the semi-arid sections under cultivation.

Since in these sections crop production is largely limited by the amount of available soil nitrogen, crop rotations including legumes are rapidly being introduced for the primary purpose of maintaining the soil nitrogen supply for the production of maximum wheat yields in a permanent system of grain farming. This maintenance of soil nitrogen is so dependent on the symbiotic nitrogen fixation of the legume bacteria that it is extremely important from an economic standpoint to know that these bacteria are present and to ascertain whether they can survive successfully in the soil during the complete cycle of the crop rotation. The semi-arid section of Eastern Washington, due to its peculiar climatic conditions, with long, cold winters of freezing and thawing followed by long dry periods with relatively high temperatures during the growing season, offers an especially favorable opportunity for this study. The experiments reported in this paper are chiefly concerned with the effect of the long, dry, and hot periods of the summer and to a less extent with the cold temperatures and relatively high soil moisture during the winter on the viability of *R. leguminosarum* in the soil.

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THE EFFECT OF TEMPERATURE AND EXTREMELY LOW AND HIGH SOIL MOISTURE ON R. LEGUMINOSARUM

An examination of the literature pertaining to the effect of temperature and soil moisture on *R. leguminosarum* shows that most of the earlier investigators agreed that these organisms are very sensitive to sunlight and desiccation. More recent studies do not entirely support this viewpoint although results are largely variable as can be seen from the typical examples which follow:

Chester (3) found that legume bacteria perish very rapidly when dried on the seed, whereas Fellers (4) and Temple (10) observed that good nodulation was produced from inoculated seeds exposed to desiccation for 5 and 9 months. It seems reasonable to conceive that the seed coat which is generally smooth and firm offers but little protection to the bacteria and that soil particles, on account of the hygroscopic film surrounding them might give the bacteria better protection against the effects of desiccation. Even as with the seeds the results here indicate wide variations. Prucha (8) found that legume bacteria inoculated in clay, sandy loam, and sand, dried subsequently under atmospheric conditions and kept dry for 46 days, were either greatly reduced in number or in their infecting power. Fellers (4) on the other hand, was of the opinion that the symbiotic nitrogen fixing bacteria may live for years in dry soil. He found that fresh soil taken from an inoculated soybean field and stored in a dry condition for 18 months caused copious nodule production on soybean plants. Perhaps the most convincing evidence in favor of the resistance of legume bacteria to sunlight and desiccation was offered by Albrecht (1) in his studies with silt loam soil. He observed that thoroughly inoculated silt loam, taken from the field and spread in a thin layer, exposed to direct sunlight for 2 months, and later stored in a dry condition for 30 months, was as good for inoculating purposes as the fresh moist soil gathered from the field.

Apparently the temperature investigators have secured more coördinating results. Jones and Tisdale (7) reported that vigorous nodules are produced in inoculated soils at any temperature at which the plant will survive. Fred (5) stated that legume bacteria are able to survive through the winter and will withstand ordinary winter temperatures.

The foregoing examples which are typical of the many varying results in the literature on the subject are sufficient to show the need of more definite knowledge along this line.

In an attempt to throw more light on these points an experiment was undertaken to determine the effect of wide variations in temperature and moisture on the development and nodule producing power of *R. leguminosarum* in sterilized Palouse silt loam. This soil is of basaltic lava formation and is highly productive. Its nitrogen content is approximately 0.18 to 0.20 per cent, its optimum moisture capacity 20 per cent, and its reaction variation from pH 5.5 to pH 6.5. The soil in general does not readily respond to lime treatments.

Fifteen ½-gallon glazed pots were filled to within 1 inch of the top with soil and sterilized in the autoclave in two intermittent sterilizations of 6 hours each at 15 pounds pressure. The pots were allowed to cool and the soil moisture was adjusted to its optimum point with distilled water. The first five pots were inoculated with a suspension of a pure culture of legume bacteria for alfalfa; the second five with a similar suspension of legume bacteria for peas; and the last five with a similar suspension of legume bacteria for clover. These sus-

pensions were thoroughly mixed with the soil in the pots and allowed to stand at room temperature for 5 days. Plate counts were taken from all the pots. Then, from each series, triplicate pots were placed out of doors to approximate field conditions. The remaining two pots of each series were placed in the greenhouse under optimum moisture and temperature conditions to serve as a control. Plate counts of all the pots were made periodically to determine the effect of the various factors on the numbers of bacteria.

TABLE 1

Average counts in millions of bacteria per gram of soil from triplicate pots out of doors and duplicate pots in the greenhouse as affected by temperature and moisture

DATE OF SAMPLING	TEMPERATURE	ALFALFA ORGANISMS		PEA ORGANISMS		CLOVER ORGANISMS	
		Moisture	Number of bacteria	Moisture	Number of bacteria	Moisture	Number of bacteria
	°F.	*per cent*		*per cent*		*per cent*	
Pots kept out of doors							
1/24	68	20.0	123.00	20.0	933.00	20.0	1,926.00
3/6	25	20.0	187.40	20.0	93.40	20.0	254.50
6/22	78	9.0	1.71	11.0	2.01	9.5	2.33
7/22	92	2.8	1.00	3.8	2.51	2.5	1.21
8/22	99	0.7	2.15	0.4	2.43	0.3	1.92
9/24	86	1.6	1.09	1.8	1.62	1.8	1.63
11/6	67	17.1	7.40	17.5	13.50	17.5	10.20
12/4	30	22.0	4.08	21.8	5.61	22.4	10.00
1/18	17	Flooded	1.59	Flooded	1.46	Flooded	1.30
4/9	14	18.0	0.442	17.8	0.408	18.1	0.353
Pots kept in greenhouse							
1/24	77	20.0	670.00	20.0	420.00	20.0	2,160.00
3/6	77	20.0	30.00	20.0	36.50	20.0	38.00
6/22	83	15.0	44.90	14.5	16.25	14.2	14.25
7/22	89	16.0	9.40	17.0	10.88	16.0	7.82
8/22	86	16.0	14.60	16.0	14.66	16.5	21.50
9/24	76	16.4	16.50	15.5	15.50	17.7	17.87
11/6	75	17.2	17.83	14.5	11.16	18.6	10.16
12/4	68	15.5	6.37	16.0	6.50	15.5	9.25
1/18	68	16.3	2.68	16.9	2.03	16.0	24.64
4/9	77	17.5	13.62	17.1	5.02	16.7	11.40

Since all the pots were exposed to contamination from the air the difficulties involved in making counts for legume bacteria alone are readily recognized, hence no claim is made that the exact numbers were determined. By using nitrogen-free agar in the plates, however, many of the contaminating forms were eliminated. In addition to this, only typical colonies of *R. leguminosarum* were counted, so the results may be said to be reliable. The samples

of soil designed for plate counts and moisture determinations were secured each time in the following manner: One-half inch of the surface soil was temporarily removed and, with a small auger, several borings were made through the remaining central portion of the soil column until sufficient soil was collected to make both determinations. The holes resulting from the borings were filled from the surrounding soil and the surface soil was replaced. Each sample was thoroughly mixed previous to weighing out 25 gm. for the moisture determination and 1 gm. for the bacterial count. The moisture was determined by allowing the samples to dry to constant weight under atmospheric conditions. The 1-gm. sample for the plate counts were shaken for 20 minutes in 99 cc. of sterile water before the usual dilutions were made. Plates were poured in quadruplicate and incubated for 7 days at 25°C. before the colonies were counted. The counts of the quadruplicate plates were averaged for each individual pot. Then the results of the triplicate pots out of doors and those of the duplicate pots in the green-house, were again averaged so that the numbers given in millions in table 1 represent the average counts of 12 plates and 8 plates respectively. The moisture and temperature determinations appear in the same table. The temperatures recorded represent the maximum temperature occurring between each two dates of sampling in the summer months, and the minimum temperature occurring between each two dates of sampling during the winter months.

The most striking feature of the experiment is that the legume bacteria inoculated in sterile soil multiplied very rapidly during the first few weeks and then decreased considerably regardless of moisture and temperature changes. This behavior may be influenced by many factors, chief of which is probably the competition of invading organisms. Under optimum moisture and temperature conditions as maintained in the greenhouse this competition seemed to establish an equilibrium wherein the legume bacteria had decreased to certain numbers, which remained fairly constant for several months. This equilibrium period was followed by a further drop in numbers which also continued for several months and was succeeded by a period during which there was a strong tendency toward the first state of equilibrium. This condition is hardly explainable on the basis of the data secured. It is conceivable that the fluctuation might be caused by a similar fluctuation in the amount of available food material, resulting from the difference in metabolic processes of the invading and the symbiotic nitrogen fixing bacteria, and the needs of the two kinds of bacteria for different food.

In the pots kept under field conditions there was a distinct correlation between the moisture content of the soil and the number of living bacteria. However, under the severest conditions of heat and drought prevailing during the months of June, July, August, and September, the reduction in numbers of viable legume bacteria was relatively small. As soon as moisture was supplied by the fall rains late in October, the bacterial numbers increased rapidly and soon reached approximately the same proportions as those in the pots in the green-

house. A rather abnormal condition occurred in the pots under field conditions when the precipitation during the winter became so great that the soil in the pots was covered with water. This was due to the fact that no drainage had been provided for in the glazed pots. This flooded condition lasted for 2 weeks and was very detrimental to the legume bacteria. In fact the reduction in their numbers due to excess moisture was much greater and lasted much longer than that caused by high summer temperatures and extremely low moisture content. The effect was still noticeable 2 months after the excess water had disappeared from the pots.

At that time—14 months after the experiment was started—sterilized seeds of the proper kinds of legumes were planted in all the pots used in the experiment, to ascertain by comparison, the effect of the apparently impaired condition of the bacterial cells of the flooded pots on their ability to produce nodules. The plants were allowed to grow for 60 days and were then examined for nodules by carefully washing the soil from the roots. Abundant nodules were found on the roots of the plants in all the pots irrespective of previous conditions. No difference could be observed between the results from the pots kept under optimum conditions in the greenhouse and those kept under the extreme hardships of field conditions. The experiment demonstrated that, in certain soils at least, legume bacteria may survive unusual exposure to wide extremes of temperature and soil moisture without any apparent effect on their ability to produce nodules on the roots of legumes.

THE LONGEVITY OF LEGUME BACTERIA IN THE SOIL IN THE ABSENCE OF THE HOST PLANT

It has been demonstrated in the previous experiment that laboratory cultures of legume bacteria are able to survive in the soil for more than a year under adverse climatic conditions. But from the economic standpoint of the farmer, it is also important to know how long they are able to survive under natural conditions in cultivated soils in the absence of the host plant. The information available in the literature on the subject is rather indefinite and variable.

Russell and Morrison (9) reported that soybean nodule bacteria are capable of living under field conditions without the host plant for a period of 17 years and that they tolerate soils with a medium to a strong acid reaction. Fred (5) stated that experience has often shown that it is unnecessary to inoculate legume seed even though no legume has been grown on the land for a number of years. Hopkins (6), on the other hand, pointed out that there is no reason to believe that any of the species of the symbiotic nitrogen gathering bacteria will live in the soil for more than a few years. He admitted that it is not definitely known just how long they live in a soil without leguminous crops, although he seemed to be quite positive that they do live for two or three years, but probably not for more than five or six years.

To obtain more definite knowledge on this point a simple experiment with soil from inoculated fields was planned. Three fields that once had been inoculated with alfalfa bacteria were located, where the alfalfa had been plowed under, 3, 8, and 13 years ago respectively. As each field was summer fallowed

during the year following the plowing of the alfalfa and nothing but cereal crops were planted subsequently, no legume plants remained to support the growth of the symbiotic nitrogen-fixing bacteria. Representative samples of soil taken to a depth of 10 inches were collected from each of these fields. Each sample was thoroughly mixed and then used to fill three 2–gallon pots. Another field was located where peas with an abundance of nodules had been grown 10 years ago and where nothing but cereal crops have been raised since that time. A composite sample similar to those taken in the alfalfa fields was collected, mixed, and used to fill three 2–gallon pots. Sterilized alfalfa and pea seeds were then planted in the proper pots and allowed to grow for 60 days. At the end of this period the soil in all of the pots was carefully washed from the roots of the plants previous to the examination for nodules. Abundant nodules were found in every case and there was no perceptible difference between the nodulation on the plants grown in soil devoid of the host plant for 2 years and that devoid of the host plant for 12 years. That these results were probably not influenced by any favorable conditions of the plant house was shown in the results with the peas. It happened that shortly after the soil sample was collected from the field, uninoculated peas were again planted in that field, and also in an adjacent field where peas had never been grown. The nodulation in the field which was inoculated 10 years ago proved to be even better than that in the pot experiment. The field where peas were grown for the first time was also examined for nodules, but only a few widely scattered plants were found to be at all inoculated. These results show that when the legume bacteria are present in the soil, they will readily form nodules on the roots of the host plant. The experiment further demonstrates that when the legume bacteria are once introduced into the Palouse silt loams of the semi-arid section of Eastern Washington they are able to live without the host plant for at least 10 or 15 years and probably for a considerably longer time. The total results of both experiments offer substantial evidence to show that the drying out of soils during long, hot, dry periods of summer is not responsible for the killing of most legume bacteria of the soil.

THE EFFECT OF DUST STORMS ON THE DISTRIBUTION OF R. LEGUMINOSARUM

According to Allen (2), wind storms, dust storms, and mud storms are negligible factors in the distribution of legume bacteria in Eastern Washington. These storms occur quite frequently in this section and considerable amounts of fine soil are thus moved about. It would seem that the greater the number of fields which are artificially inoculated the greater would be the possibility for inoculating new fields by means of the wind blown dust. Since the results in the two previous experiments show that the legume bacteria are able to live in the soil for many years and that they can withstand desiccation for a considerable length of time, a third experiment suggested itself to determine the extent of the distribution of these bacteria as a result of wind action. Nine 2-gallon pots were filled with Palouse silt loam and sterilized in the autoclave as

in the first experiment. When cool they were placed out of doors where they were exposed to the natural atmospheric conditions for 16 months. Then triplicate pots were planted with sterile seeds of alfalfa, peas, and clover respectively. From 5 to 10 plants were allowed to each pot and 60 days after planting the plants were examined for nodules in the usual way. The nodules were counted and the results are given in table 2.

Only two pots were free from nodules. The others had only a limited number, but this was sufficient to show that viable legume bacteria are moved about by the wind and dust storms and that inoculation is possible by means of these factors. It is doubtful whether this natural means of inoculating has been effective to any marked extent in the past, for it has been the common experience that artificial inoculation by means of inoculated soil or laboratory cultures was necessary to secure thorough inoculation in fields planted to legumes for the first time. However, a few scattered inoculated plants can generally be found in new legume fields where artificial inoculation has not been practiced. As more fields become inoculated by artificial means the effect of the

TABLE 2

Nodulation in sterilized soil subsequently exposed to wind and dust storms for 16 months

	TOTAL NUMBER OF NODULES ON 5 TO 10 PLANTS		
Pot number	Alfalfa	Peas	Clover
1	0	4	3
2	9	0	5
3	4	3	2

wind and dust storms in the distribution of legume bacteria will increase proportionately. Although these factors may never be sufficiently effective to insure and maintain thorough inoculation in the soils of Eastern Washington they constitute a means of natural distribution which should not be entirely overlooked.

SUMMARY

Pot experiments carried on in the greenhouse and out of doors demonstrated that laboratory cultures of *R. leguminosarum* grown in Palouse silt loam are capable of surviving unusual exposure to wide extremes of soil moisture without any apparent effect on their ability to produce nodules on the host plants.

Excessive soil moisture to the point of saturation or flooding was much more detrimental to the life of these bacteria than extreme dryness approaching air-dry conditions.

The extremes of temperatures of winter and summer did not prove to have any injurious effect on the nodule production of the legume bacteria in the soil.

Legume bacteria for alfalfa, peas, and sweet clover, once introduced into the

semi-arid soils of Eastern Washington readily produce nodules and are able to survive in the soil for 10 to 15 years or longer in the absence of the host plant.

Legume bacteria proved to be distributed by wind and dust storms, but not to the extent of causing a thorough inoculation of legumes which are planted in the fields for the first time.

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EFFECT OF LOCAL INFLUENCES IN MODIFYING THE GENERAL ATMOSPHERIC CONDITIONS[1]

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A statistical study was made of the effect of local influences in modifying the general atmospheric conditions that exist in certain sections of Wisconsin.

Central Wisconsin soils are mainly light textured, the sandy members being the most abundant. North and south of this area the soils are mainly silt loams. As there is thus a distinct sandy soil covering a large area in central Wisconsin an opportunity seemed to be provided to ascertain whether the nature of the soil there exerted any marked influence on such climatic factors as temperature and rainfall.

In 1906 Henry (5) referred to this central area as follows:

> There appears to be a rather remarkable deficiency of precipitation in the vicinity of the Winnebago basin as shown by the records of Hancock, Fond du Lac, and Stevens Point, the average annual precipitation at these stations being nearly 4 inches less than that of surrounding points. It does not seem probable that such a marked difference could occur in so limited an area, especially where no marked topographical features exist, and while the accuracy of the measurements made at these stations is not questioned, the period of observations, about 10 years, is too short to determine with certainty whether this discrepancy is actual or only apparent.

The records as obtained by the United States Weather Bureau (7) at certain stations over a period of years—since their establishment up to 1920 inclusive—were studied. At Hancock, which lies in the sandy area of Central Wisconsin, the United States Weather Bureau station was located from 1903 to 1920 on a farm. Surrounding country is level and there are no bodies of water or timber near. At Madison, which lies south of Hancock in the silt loam area, from 1878 to 1920 the instruments were located on one of the buildings of the University of Wisconsin in the city of Madison. This building is on a high ridge between lakes. The third station selected was Wausau, which lies north of Hancock out of the sandy area and where the instruments were exposed on the courthouse lawn during the 22 years previous to 1921. The station at Wausau was situated a few hundred feet from the Wisconsin River surrounded by hills.

[1] Part 2 of a thesis submitted at the University of Wisconsin in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

The author wishes to express his appreciation for the helpful suggestions and criticisms tendered by Professor A. R. Whitson.

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A study of the data obtained during the years mentioned shows that Madison has a higher mean temperature for each month of the year than either of the other two stations, whereas Wausau has the lowest mean temperature for every month. The mean July temperature as shown by this data at Hancock was 71.7°, at Madison 72.1°, and at Wausau 68.4°.

The average rainfall during these same years was: Wausau 31.68 inches, Hancock 31.49 inches, and Madison 31.18 inches. A slight decrease in rainfall is thus indicated toward the most southern station (Madison), but the distribution was not the same at these three localities. During the early part of the growing season from April to June inclusive, the mean rainfall at Hancock was higher than at either of the other stations, but during July, August, and September it was highest at Wausau. During the months of April to September inclusive, the mean monthly rainfall was lowest at Madison. The greatest difference for the mean monthly rainfall between these stations was 0.70 inch, and that was for May when Hancock had 4.48 and Madison 3.78 inches.

Several stations were next selected in the sandy area to ascertain whether their records varied considerably from each other. The localities selected were Hancock, Wisconsin Rapids, Stevens Point, Meadow Valley, Mather, Valley Junction, and Hatfield. The length of the record for these localities varied from 17 years for Mather to 28 years at Hancock. Mather was the only station at which the mean monthly temperature deviated widely. This was no doubt due to the fact that Mather is situated in a swampy area. The mean annual temperature at Mather was 42°F. and at Hancock 44.4°F. whereas at the other stations it varied from 43.3 to 43.7°F.

Two stations at approximately equal distances from Hancock were next selected. Merrill, which lies 72.5 miles due north of Hancock, and Madison, 75 miles due south of Hancock, were chosen as being in silt loam areas, and their records compared with Hancock, which is in the sandy area. The decrease in temperature northward from Madison through Hancock to Merrill was not uniform when the mean temperatures for April to September inclusive were compared. The mean temperatures at Hancock for each month, April to September inclusive, are very near to those of Madison and not midway between those of Merrill and Madison as one might at first expect.

A like comparison was then made between the temperature records at Tomahawk, which is 95 miles north of Hancock; at Brodhead, which is 108 miles south of Hancock; and at Hancock. The mean temperatures for the growing season, April to September inclusive, at Hancock were closer to those of Brodhead than to Tomahawk, thus again indicating a higher temperature at Hancock than would be indicated by a fairly uniform decrease in temperature from the southern station to the most northern station.

In comparing temperatures for stations in Wisconsin the nature of the soil is likely to have an influence only during those months when there is no snow cover and for this reason it is felt that the comparison of the temperatures

during the growing season is the most logical. All data hereafter given, therefore, are limited to these months.

A large number of Weather Bureau stations which lie in an almost north-south line were next selected and included Brodhead, Madison, Portage, Hancock, Stevens Point, Wausau, Merrill, and Tomahawk.

In this case the temperatures in the sandy area lie close to what the normal decrease in temperature from the most southern to the most northern station would indicate them to be.

As the weather of August in Wisconsin is thought by some to be less subject to the influence of cyclones or thunderstorms than any other month it is perhaps best to discuss further the mean temperature for August in and out of the sandy area. The stations selected next were Brodhead, Madison, Portage, Hancock, Stevens Point, Wausau, Merrill, and Tomahawk running from south to north. Corrections—1°F. for every 270 feet—were made for the differences in elevation—1091 feet, at Hancock; 812 feet, at Brodhead; 1450 feet at Tomahawk. The mean August temperatures of the sandy area were decidedly above the normal mean temperature for that latitude, for the decrease in temperature from Brodhead northward to Tomahawk was not uniform, especially over the sandy area. The data used here were for the years beginning with the establishment of the stations up to 1920 inclusive (6).

A comparison of the rainfall records of stations in and out of the sandy area failed to show any decided difference. One reason for this is the shortness of the records and the occasional heavy rainfall which may come at just one of the stations. In June, 1914 at Hancock in the sandy area the total precipitation was 11.75 inches, whereas at Madison in the silt loam area south, it was 3.46, and at Merrill north of the sandy area it was 7.10 inches. It is felt by the writer that no definite conclusion can be drawn regarding the influence of the sandy nature of the soils of Central Wisconsin on the rainfall, as the length of the record is not sufficient.

As the study up to this point failed to show in the sandy area any marked difference in rainfall due to the nature of the soil, but as there may be an increase in temperature, it was decided to compare the temperatures of the stations in this sandy area with those situated in the same latitude in Wisconsin and Minnesota.

One of the earliest notices of variations from the latitude normals was taken in 1791,[3] but the causes named we now consider inadequate, although the remarks are of historic interest. Hann (4) summarized the effect of land and water in modifying the normal latitudinal temperature.

The word "anomaly" first used in connection with temperature by Cotte, was taken up by Dove in his "Distribution of Heat over the Surface of the Globe." This famous work published in 1852, contained the first charts of Isanomalous Temperatures; they were dedicated to Humboldt, the inventor of isotherms. In 1878 a valuable addition was made to the subject

[3] *Obs. Phys.* 39: 42, Paris 1791.

of isanomals by Teisserenc de Bort (8). In these charts the advance over Dove's work was especially noteworthy in the increased deformation of the lines of equal departure, or isanomals. The observations of the "Challenger" Expedition, made by Buchan were the basis for the publication of Batchelder's Isanomalous Temperature Charts (1). In the preparation of these charts, the records from 1870 to 1885 were used and the causes of the irregularities of temperature distribution were grouped under two heads—the irregular distribution of the land surfaces of the globe, or continental interruptions, and the circulation of the waters of the globe in fixed and natural directions, or ocean currents. The Sahara, a sandy and rocky plateau near the equator, has conditions where absorption and radiation are very high. In summer this region warms to a maximum of 16°F. above the normal of its latitude, but in winter, despite its nearness to the equator and the warm Mediterranean and Red seas, it actually falls below its latitude mean temperature, as do the similar Arabian desert nearby and the desert in Australia. In like manner Connolly (2) has shown the unequal distribution of temperature in preparing his charts on the "Annual Ranges of Temperature."

TABLE 1

Average mean temperatures 1913–1919

Corrected to elevation of 976½ feet

STATIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	GROWING SEASON
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Rochester	45.4	55.9	65.7	71.7	68.6	59.9	61.2
Faribault	46.3	56.7	65.7	72.0	69.0	60.5	61.7
St. Peter	47.9	57.6	67.1	73.2	70.3	61.3	62.9
Winnebago	47.0	57.7	67.5	74.0	71.0	61.5	63.1
Zumbrota	46.1	55.9	64.6	70.8	68.1	59.6	60.7
Meadow Valley	45.0	55.1	64.1	70.3	66.7	58.5	60.0
Pine River	45.0	55.4	64.9	70.6	67.3	59.4	60.3
Mather	43.1	53.7	62.8	68.9	65.0	56.7	58.4
Hancock	46.7	57.0	66.5	72.5	70.3	61.3	62.6
Latitude Mean	45.8	56.1	65.4	71.5	68.5	59.8	61.2

The records for the years 1913–1919, inclusive, were used in this study, for during this period according to the records of the United States Weather Bureau the thermometers used at the stations selected in Wisconsin and Minnesota were not moved. A longer period of years could not be used because at some of the stations the location of the thermometers was changed. All the stations selected in Wisconsin and Minnesota lie on or close to latitude 44° 8′ north. The stations selected in Minnesota were Rochester, Faribault, St. Peter, Winnebago, Zumbrota; and in Wisconsin, Meadow Valley, Pine River, Mather, and Hancock. The elevation of these nine stations above sea level ranged from 840 to 1100 feet and therefore that of Meadow Valley, which was midway between the extremes at 976½ feet, was taken as the standard elevation.

As all of these stations were in approximately the same latitude the average of the records for each month is called the latitude mean and is given at the bottom of the table.

The departures of the stations located in Wisconsin from the latitude mean are shown in figure 1. The departures in the mean temperature at Hancock during the growing seasons of 1913–1919 are seen to be consistently above the latitude mean whereas those at Pine River, Meadow Valley, and Mather are below. In the immediate vicinity of the thermometers at these latter three stations there are areas of peat, muck, or swamps whereas at Hancock the soil is more predominately a sand.

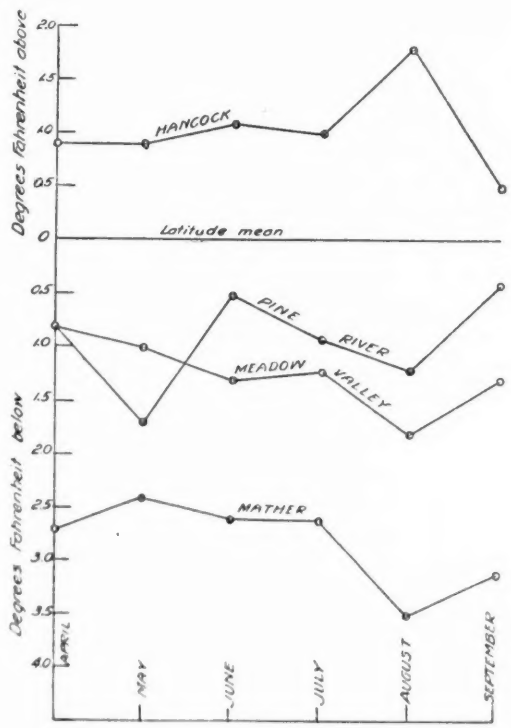

FIG. 1. MEAN TEMPERATURE RANGE DEPARTURES FOR 1913–1919

The mean maximum temperatures at these nine stations, which are approximately in the same latitude, were then compared. The data used are given in tables 2 and 3.

From the figures in the last column of table 3 it is evident that Mather has a lower mean maximum temperature during the growing season, that is from April to September inclusive, than the other stations. Hancock, on the other hand, has the highest mean maximum temperature of the Wisconsin stations and, if the mean for the growing season is taken as a basis, it is 3.3°F. higher

than at Mather. The mean maximum temperatures for the growing season for the same latitude at the Wisconsin and Minnesota stations is 88.6, whereas for Hancock it is 89.5 and for Meadow Valley 89.1°F. The departures from the latitude mean for the Wisconsin stations are shown in figure 2, which is based on table 3. A comparison of figures 1 and 2 shows that the temperatures at Hancock during the growing season were above the latitude mean whereas

TABLE 2

Mean maximum temperatures during growing seasons 1913–1919

STATIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	GROWING SEASON
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Rochester	79.0	89.3	90.7	96.3	93.0	89.9	89.7
Faribault	77.0	87.7	88.6	92.7	90.8	86.4	87.2
St. Peter	78.0	88.6	91.3	95.7	94.7	89.3	89.6
Winnebago	79.4	91.3	93.4	97.1	94.6	90.4	90.9
Zumbrota	77.0	87.3	87.0	92.4	92.1	87.0	87.3
Meadow Valley	76.3	88.1	90.7	97.1	94.4	88.3	89.1
Pine River	76.3	88.0	87.9	95.9	91.9	87.3	87.9
Mather	74.9	84.6	86.7	93.9	91.0	86.3	86.2
Hancock	76.0	88.0	91.0	97.4	94.1	87.3	89.0

TABLE 3

Mean maximum temperatures during growing seasons 1913–1919

Corrected to elevation of 976½ feet

STATIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	GROWING SEASON
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Rochester	79.0	89.3	90.7	96.3	93.0	89.9	89.7
Faribault	77.1	87.8	88.7	92.8	90.9	86.5	87.3
St. Peter	77.5	88.1	90.8	95.2	94.2	88.8	89.1
Winnebago	79.9	91.8	93.9	97.6	95.1	90.9	91.4
Zumbrota	76.8	87.1	86.8	92.2	91.9	86.8	87.1
Meadow Valley	76.3	88.1	90.7	97.1	94.4	88.3	89.1
Pine River	76.0	87.7	87.6	95.6	91.6	87.0	87.6
Mather	74.9	84.6	86.7	93.9	91.0	86.3	86.2
Hancock	76.5	88.5	91.5	97.9	94.6	87.8	89.5
Latitude Mean	77.1	88.1	89.7	95.4	93.0	88.0	88.6

those at Mather were always below this mean. This applies to the mean temperatures for the growing season as well as to the mean maximum temperatures for the same period. In case of Pine River and Meadow Valley, these two figures are not in agreement, for in figure 1 both of these stations lie below the latitude mean whereas in figure 2 Meadow Valley is comparable to Hancock, and Pine River is more like Mather except during the month of May.

As has been stated, the Hancock Weather Bureau Station is located in the more typical sandy soils of Central Wisconsin but when this study had reached this point the writer felt that the varying results obtained at the other Wisconsin stations indicated that perhaps sufficient detailed information relative to the immediate surroundings of the thermometers was lacking. Information was obtained from the Hancock substation of the College of Agriculture,

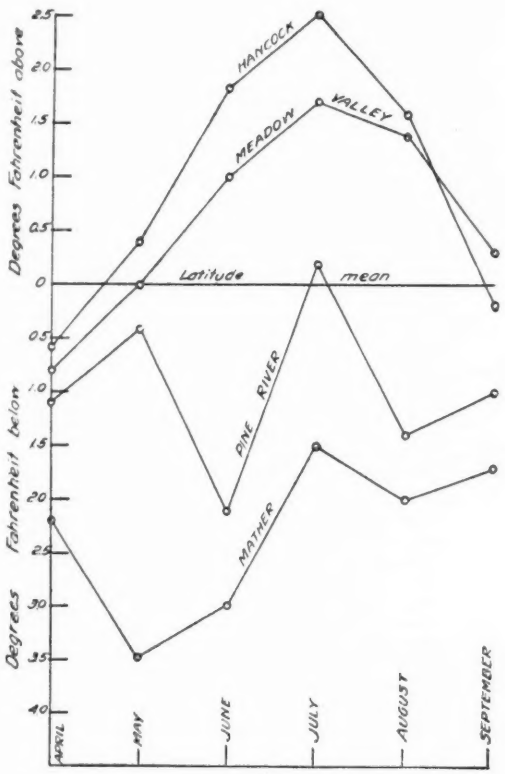

FIG. 2. MEAN MAXIMUM 1913–1919 DEPARTURE FROM LATITUDE MEAN

University of Wisconsin,[4] which showed that the thermometers at Hancock were moved in 1910. This was not indicated in the Weather Bureau records[5] (3).

[4] Personal communication to the author, dated May 10, 1924.

[5] Personal Communication to the author, dated March 20, 1924 from the Milwaukee headquarters of the Weather Bureau, United States Department of Agriculture.

In 1910 the village hall at Hancock, a brick building about 25 feet high, was built on the site occupied by the thermometers. The thermometers were then moved (1910) to the top of a lean-to about 15 feet south of the village hall and at the rear of a two-story frame building. As the previous studies were based on the information that the shelter for the thermometers was 5½ feet from the ground and later it was ascertained that this shelter was on a lean-to 15 feet above the ground it is certain that the nearness to these buildings and the distance from the ground were conditions influencing the use of temperature data so obtained.

The thermometers were moved from this lean-to in 1921 to the Hancock substation of the College of Agriculture, University of Wisconsin. The description of the present location (since 1921) was furnished by the United States Weather Bureau. The thermometers are now located 1088 feet above sea level; over sod 70 feet south of house; 70 feet north of barn; 50 feet east of a tree; floor of shelter is 50 inches above ground. The topography is level with a low ridge

TABLE 4

Mean temperatures for 1922, 1923

STATIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	GROWING SEASON
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Faribault	45.6	60.5	69.6	72.1	70.4	64.7	63.8
St. Peter	46.9	61.3	71.3	73.6	71.9	66.5	65.3
Winnebago	45.8	60.1	70.3	73.1	71.2	65.0	64.3
Zumbrota	45.2	60.0	69.2	72.0	70.5	63.8	63.5
Meadow Valley	43.6	59.0	68.0	70.1	67.2	61.4	61.6
Pine River	43.7	60.1	68.3	70.1	67.9	61.5	61.9
Mather	42.9	58.1	67.1	69.1	66.0	60.4	60.6
Hancock	42.9	59.7	68.9	70.4	68.1	61.6	61.9

½ mile east; small lake 1 mile northeast; and a thin grove 5 rods west. This station is one mile due south from the station formerly in the town of Hancock and the date of the first observation was August 31, 1921.

It is unfortunate that there are only two years' records at present for the new location at Hancock; nevertheless, these might give an indication of the effect of the local conditions on temperature. The records of the eight stations which are in the same degree of latitude in Wisconsin and Minnesota were again compared by using the average of the 1922 and 1923 monthly data. Rochester, Minnesota was also previously used but could not be used again as there are no records for that station for these years. The actual mean temperature for the different months of the growing season at these nine stations is given in table 4 for the two years mentioned (3). The average for the six months is also shown in the last column. Corrections were next made, as previously, for the difference in elevation by converting to the same elevation, namely that of 976½ feet, which is the elevation of the instruments at Meadow

TABLE 5

Mean temperatures during growing seasons 1922 and 1923

Corrected to elevation of 976½ feet

STATIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	GROWING SEASON
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Faribault	45.7	60.6	69.7	72.2	70.5	64.8	63.9
St. Peter	42.4	60.8	70.8	73.1	71.4	66.0	64.8
Winnebago	46.3	60.6	70.8	73.1	71.7	65.5	64.8
Zumbrota	45.0	59.8	69.0	71.8	70.3	63.6	63.3
Meadow Valley	43.6	59.0	69.0	70.1	67.2	61.4	61.6
Pine River	43.4	59.8	68.0	69.8	67.6	61.2	61.6
Mather	42.9	58.1	67.1	69.1	66.0	60.4	60.6
Hancock	43.4	60.2	69.4	70.9	68.6	62.1	62.4
Latitude Mean	44.6	59.9	69.1	71.3	69.2	63.1	62.9

TABLE 6

Mean maximum temperatures for 1922 and 1923

STATIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	GROWING SEASON
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Faribault	75.5	85.0	93.5	91.5	92.5	92.0	88.3
St. Peter	77.0	85.0	96.5	96.5	95.0	97.0	91.3
Winnebago	75.0	84.5	95.5	94.0	94.5	93.0	89.4
Zumbrota	75.0	83.5	93.5	94.5	95.0	95.0	89.4
Meadow Valley	77.5	87.5	94.5	92.0	94.5	95.5	90.3
Pine River	77.5	86.0	94.0	91.0	92.0	91.5	88.7
Mather	76.5	87.0	92.0	90.5	93.5	94.0	88.9
Hancock	75.0	85.0	94.0	92.0	93.5	93.0	88.8

TABLE 7

Mean maximum temperatures for 1922 and 1923

Corrected to elevation of 976½ feet

STATIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	GROWING SEASON
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Faribault	75.6	85.1	93.6	91.6	92.6	92.1	88.4
St. Peter	76.5	84.5	96.0	96.0	94.5	96.5	90.8
Winnebago	75.5	85.0	96.0	94.5	95.0	93.5	89.9
Zumbrota	74.8	83.3	93.3	94.3	94.8	94.8	89.2
Meadow Valley	77.5	87.5	94.5	92.0	94.5	95.5	90.3
Pine River	77.2	85.7	93.7	90.7	91.7	91.2	88.4
Mather	76.5	87.0	92.0	90.5	93.5	94.0	88.9
Hancock	75.5	85.5	94.5	92.5	94.0	93.5	89.3
Latitude Mean	76.1	85.4	94.2	92.8	93.8	93.9	89.4

Valley. These corrected mean temperatures are given in table 5. The latitude mean given in table 5 is the average for the eight stations for the particular month or for the growing season. As the previous studies have shown and as this latter table likewise indicates, the temperatures at Mather were below the latitude mean for every month. The same was true during these two years at Pine River and Meadow Valley. The records in table 5, however, show that at Hancock the temperatures were generally only slightly below the latitude mean and in May and June they were slightly higher.

These eight stations were next compared by using the mean maximum temperatures for the same months during 1922 and 1923 (table 6). Corrections for differences in elevations were again made as before (table 7). There is no consistent difference between the mean maximum temperatures at Hancock and the latitude mean. During the month of August when cyclonic storms are less common in Wisconsin and Minnesota and during 1922 and 1923 the mean maximum temperature is given as 94.0 at Hancock whereas the latitude mean is slightly lower (0.20°F.).

A period of two years is too short for comparisons between stations, as slight irregularities in the instruments, inaccuracy of readings, and many other factors may serve to bring in slight discrepancies which are highly magnified in such a brief record. It was thought advisable, therefore, to study the temperature records for the month of August over a longer period of years and to ascertain if possible whether the change in the location of the instruments at Hancock had influenced the temperatures. The records from 1905 to 1923 inclusive were therefore compared at three stations in central Wisconsin—at Pine River and Meadow Valley where the thermometers were in the same locations between 1905 and 1923 inclusive, and at Hancock. In figure 3 are shown the August maximum temperatures for these three stations for the years 1905 to 1923 inclusive. The years 1920 and 1921 are omitted, as records were not obtained at all of these stations during these two years.

At Hancock from 1905 to 1910 the average August maximum temperature is shown as 91.7, from 1911 when the instruments were on the lean-to already referred to until 1919 the average August maximum temperature was 94.0 and for 1922 and 1923 when the instruments were at the Hancock substation the average was 93.5 or 0.5°F. less than when they were on the lean-to. In comparison with Hancock, the average August maximum temperature at Pine River from 1905 to 1910 was 90.7; from 1911 to 1919 it was 91.4; and for 1922 and 1923 it was 92.0°F. These latter figures show a progressive increase during the three periods chosen. The average August maximum temperature at Meadow Valley during the first period, 1905–1910, was 93.7, from 1911 to 1919 it was 93.4, and during the last period, 1922 and 1923, it was 94.5°F.

A comparison of the third period with the second shows that at Pine River as well as Meadow Valley the average August maximum temperature was higher than during the first or second periods. At Hancock the average August maximum temperature during the third period was 0.5°F. lower than

during the second period but the average of the second period was 2.3°F. higher than during the first period.

If the average August maximum temperatures for the third period are compared with the first period it is found that at all three stations it was highest during the third period to the following extent, Hancock 1.8, Pine River 1.3, and Meadow Valley 0.8°F. That during the years 1911 to 1919 inclusive, the thermometers at Hancock were on a lean-to seems to be reflected in the records

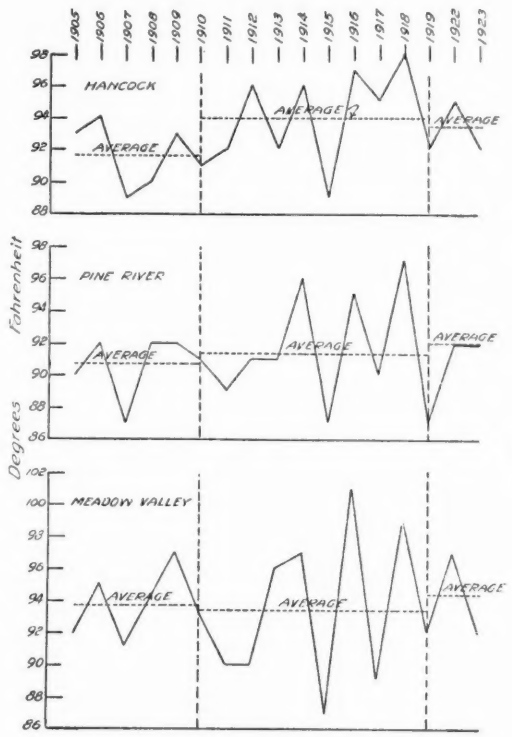

FIG 3. AUGUST MAXIMUM TEMPERATURES

obtained, for the average for these years at Hancock is much higher than during the previous period 1905 to 1910 when they were further away from the building and over sod. The radiation and reflection of heat from the lean-to and main building would result in a higher maximum temperature being recorded. During the years 1911 to 1919 inclusive, the records obtained at the other two stations do not show such a large increase in temperature over the first period, in fact one, namely Meadow Valley, shows a decrease.

That the average of the third period (1922, 1923) at Hancock is only slightly lower than the average for the second period whereas at the other two stations the average August maximum temperature for the third period is higher than for the second period is further evidence that the average for the second period at Hancock is higher than if the instruments were placed away from buildings and close to the ground.

The average for the third period at Hancock when the instruments were better located, from the writer's viewpoint, is 1.8°F. higher than for the first

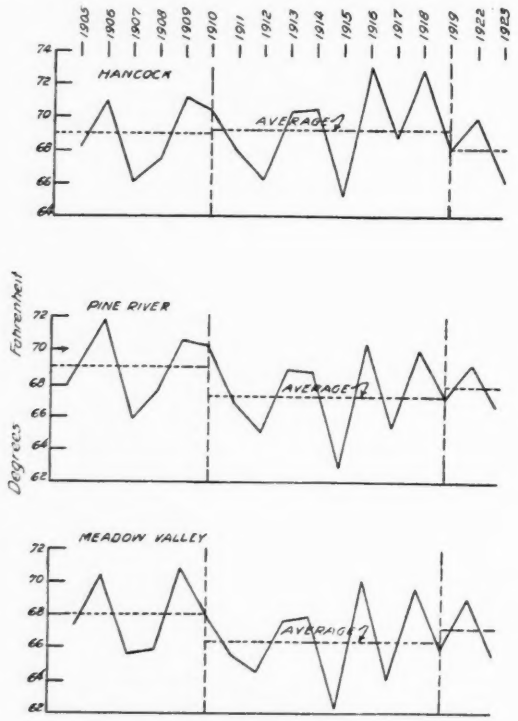

FIG. 4. MEAN AUGUST TEMPERATURES

period. This is a greater difference than was the case at the other two stations, which seems to indicate that the sandy nature of the soil at Hancock has the effect of producing a slightly higher air temperature. As previously stated, at the other two stations there are areas of peat and muck as well as sand, which, on account of their high moisture content, would offset any affect the drier sand might have in increasing the air temperatures.

A further comparison of the temperature records for these three stations was made by using the mean August temperature for the same years as for the

preceding study. The results are shown graphically in figure 4. The curves for the three stations are remarkably uniform. At Pine River the average of the mean August temperatures for the second period 1910–1919 was 67.2°F., or 1.8° lower than for the first period 1905–1910. The same was true at Meadow Valley where the average for the second period was 66.3 or 1.7°F. lower than for the first period. If the same comparison is made for Hancock the results are different, for the average of the second period there was 69.2 which was 0.2°F. higher than the average of the first period. This seems to indicate that the average for the second period was higher than it should have been.

If the average for the third period 1922, 1923 is compared with that for the first period 1905–1910 it will be seen that at each of the three stations the average for the first period was the highest. At Hancock, where the average for the first period was 69, at Pine River 69, and at Meadow Valley 68, the average for the third period at each of these stations was 68.1, 67.8, and 67.2°F. respectively.

In like manner if the third period is compared with the second period it is evident that at Hancock the average of the third period is below that for the second period whereas at the other two stations the average of the third period is above that for the second period.

The results given seem to the writer to be sufficient to show that during the period 1910 to 1919 inclusive when the thermometers at Hancock were on the lean-to previously referred to, the records obtained were higher than would have been the case if the shelter for the instruments had been placed further away from any building. In the future after a longer record has been obtained at Hancock with the instruments in their present location on the substation Farm of the College of Agriculture, a more accurate comparison will be possible between this station and others favorably situated in the sandy area as well as in the silt loam areas north and south of the sandy area.

SUMMARY

A comparison of the rainfall and temperature data obtained by the United States Weather Bureau at stations located in Wisconsin and Minnesota made over a varying period of years, for the same period, for the growing season and for individual months to ascertain whether the sandy nature of the soil in Central Wisconsin would influence these climatic elements, showed that the effect was very small.

If the conditions of sandiness and relative lack of cover do affect temperature at all, the effect is too small to be shown in the observations made by the Weather Bureau. If it were possible to place thermometers with greater care and in better locations for the purpose, it might be possible to show a small effect of soil texture on climate.

The placing of a thermometer in a shelter house on a sheet iron lean-to resulted in raising the temperature reported for the vicinity of Hancock, which

is in the sandy area of Central Wisconsin. At those stations in whose vicinity there were large bodies of water, the effect of the water in reducing the average temperatures during the warmer period of the year is clearly shown.

Any effect that the sandy nature of the soil in Central Wisconsin might have on the rainfall of this section can not be detected in the data that are at present available. Although this sandy soil does have a low water holding capacity, it has as good an opportunity of obtaining water as the heavier soils have, and the sandy nature of the soil does not tend to raise the air temperature unduly.

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METHOD OF PREPARATION OF SOIL SUSPENSIONS AND DEGREE OF DISPERSION AS MEASURED BY THE WIEGNER-GESSNER APPARATUS[1]

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Introduction and Statement of Problem

The purpose of the mechanical soil analysis is to obtain the degree of dispersion of a soil in water suspension. The method of preparation and the apparatus to be employed for such analyses depend upon the purpose for which the analyses are made. If the relationship between the colloidal fraction of the soil and its content in exchangeable cations is sought, then the basis of the mechanical analyses must rest upon the complete dispersion of all colloidal material within certain set dimensions. Perhaps this may be reached only by such methods as are employed by Hissink in his use of the Atterberg and Kopecky methods. Again, if one desires to study the dispersion of a soil under more natural conditions, then a method such as the continuous registering device of Odén, or the apparatus of Wiegner, is preferable. It is not impossible that the manipulation of such refined methods—and the preparation of the soil sample for analysis—may reach the ultimate dispersion of all material in the colloidal state in the soil. Hence, despite numerous and fundamental investigations, a yet unsolved problem, in the mind of the author, is the question of the method of preparing the soil sample for the mechanical analysis.

The degree of dispersion of a soil is largely dependent on the presence of very small amounts of electrolytes which are contained in the soil and in the water. In the sedimentation apparatus of Wiegner-Gessner (3, 7), it is easy to show that as little as $\frac{1}{10,000}$ to $\frac{1}{100,000}$ normal electrolyte solutions influence the dispersion of certain soil particles. The sensitiveness differs according to the size of the particle and according to its chemical nature. From investigations carried out by R. Gallay (2), in special cases, the fraction between 5 to 25μ in diameter is especially sensitive. The clay particles change their

[1] Translated and arranged by R. M. Barnette, Assistant Chemist, Soils, University of Florida, Agricultural Experiment Station, Gainesville.

[2] Agricultural Laboratory. From experiments made in coöperation with R. Gallay, Aeg. Tschudi, and R. M. Barnette.

flocculation value toward a definite electrolyte according to the nature of the adsorbed cation. Lithium-, sodium-, ammonium-, potassium-, rubidium- and caesium-clays are in the order named increasingly sensitive toward coagulation; correspondingly, the electrolyte sensitiveness increases in the series magnesium-, calcium-, strontium-, and barium-clays—in clays with two-valenced cations. The sensitiveness concurs with the so-called ion-hydration, which is correlated with the atom structure (8). The electrolyte content of the dispersing medium, together with the nature of the cations of the outer ion-sheath of clay, determines the magnitude of the electrical potential of the double-sheath of the suspended particle. Two cases are now to be differentiated:

1. If the potential of a part of the particles is under a critical value of definite magnitude at a certain electrolyte content, then a part of these clay particles adheres by collision, caused either by the Brownian movement of the smaller, or sedimentation movement of the larger, particles; and a partial or slow coagulation starts. If all the particles have a potential under the critical value, then every collision of particles becomes active, resulting in a so-called rapid or complete coagulation.
2. If the individual particles are charged above the critical potential, as may be the case in soil suspensions low in electrolyte content, then the collisions of the particles, caused either by the Brownian movement or by sedimentation, are so elastic from electrical repulsion, that no mutual adhesion and no coagulation result. The energy of electrostatic repulsion overcomes that of the mechanical collison. The suspension does not flocculate and the individual particles remain as such.

The methods of preparation, as used to date, change, on the one hand, the number of collisions of particles through increased movement (physical preparation by shaking, cooking, rubbing); or on the other hand, they change the potential (addition of a chemical, as ammonia).

The first group of physical influences must work differently depending on whether the particles in the dispersing medium, water, are charged above or below the critical potential. If extremely small amounts of foreign electrolytes are present, then the particles are charged above the critical potential, and the addition of kinetic energy, i.e., through cooking, causes dispersion. If, on the other hand, there are enough electrolytes in the dispersing medium that the particles have a smaller potential than the critical; then the increase of particle collisions through cooking, etc. decreases the dispersion of the suspension. Therefore the same method of mechanical preparation may lead to opposite final effects depending upon the electrolyte content and the magnitude of the charge on the particles. For example, cooking may disperse soil suspensions low in electrolyte content with particles above the critical potential, or it may coagulate suspensions with high electrolyte content and with particles below the critical potential. As a result, there is no absolutely effective way of preparation and every mechanical preparation is in effect dependent upon the electrolytes present in the suspension.

Experimental Results

THE DEGREE OF DISPERSION OF A SOIL SUSPENSION PREPARED BY SHAKING, BY RUBBING, OR BY COOKING[3]

The following data of R. Gallay (2) demonstrate that the electrolytes in the soil suspension have an influence on the effect of shaking, rubbing, or cooking as preparation methods. The same sample of a clay soil was subjected to the following treatments: 1. Six hours shaking in machine; 2. One hour rubbing by the Beam (1) method; 3. Cooking one hour with reflux condenser.

The same soil sample is always used, an advantage which this apparatus alone offers; in that the individual soil fractions are not isolated, but merely registered. One may repeat each experiment on the same sample as often as desired. The total range of dispersion was taken by the registering device of Gessner (3).[4] The tables are calculations from the sedimentation curves. The soil was first investigated without washing. Sixty grams of soil was shaken with distilled water by method 1, afterward the sample was cooked for one hour with a reflux condenser by method 3. The data of table 1 were calculated from the dispersion curves. The cooking here resulted in the flocculation of the finest fraction of the soil. The particles of the finer portion of the soil, which had not been freed from the electrolytes, was probably charged under the critical potential. The cooking increased the activity of the Brownian movement which increased the number of collisions, this in turn led to a partial mutual agglomeration. The number of smallest particles was decreased thereby. Therefore cooking coagulated the suspension.

The action of cooking is different if the soil is freed from electrolytes. Then the particles have a potential that is greater than the critical. The movement of particles, increased by cooking, leads to a mechanical dispersion; the potential is further increased by the hydrolysis of the clay. The experiment with the sample of the soil which had been washed free from electrolytes confirms this conjecture.

A sample of the same soil, which was coagulated formerly by cooking, was washed with distilled water for several days through an unglazed procelain filter. The washing was carried out here, and in all other cases, in such a manner that the filter cup was placed in the soil suspension; and the dispersing medium drawn from outside into the cup and away by suction. This washed soil was shaken in the machine for 6 hours as in method 1; then the same sample, from which the water was evaporated, was rubbed, as in method 2; finally the

[3] Experiments by R. Gallay.

[4] A comprehensive description of the device together with typical sedimentation curves and the methods of calculation are given by Gessner (4). Odén (6) also gives a review of this method and also discusses Wiegner's method of calculation. The sedimentation curves obtained in these experiments are filed at the Agricultural Chemical Laboratory of the Eidgenössische Technische Hochschule. Because of the large space requirements, reproduction of the curves and their solution is not practicable.

TABLE 1

*The degree of dispersion of an unwashed clay soil, prepared by shaking and cooking**

DIAMETER OF PARTICLES	METHOD 1. SHAKING FOR 6 HOURS	METHOD 3. COOKING FOR 1 HOUR WITH REFLEX CONDENSER
mm.	*per cent*	*per cent*
Under 0.02	47.0	42.1
0.05–0.02	34.1	37.8
0.1 –0.05	13.3	13.0
0.2 –0.1	2.9	2.5
2.0 –0.2	1.8	2.1
Total.....	99.1	97.5

* Data calculated from the registered sedimentation curves.

TABLE 2

*The degree of dispersion of the clay soil used for the data in table 1, washed, then the same sample shaken, then rubbed, and finally cooked**

DIAMETER OF PARTICLES	METHOD 1. SHAKEN	METHODS 1 AND 2. SHAKEN, THEN RUBBED	METHODS 1, 2, AND 3. SHAKEN, RUBBED, COOKED
mm.	*per cent*	*per cent*	*per cent*
Under 0.02	49.0	53.7	54.9
0.05–0.02	33.6	31.1	29.3
0.1 –0.05	11.5	8.9	8.8
0.2 –0.1	3.0	3.3	3.5
2.0 –0.2	2.4	2.8	3.0
Total.....	99.5	99.8	99.5

* Data calculated from the registered sedimentation curves.

TABLE 3

*The degree of dispersion of a clay soil used for the data in table 2, washed, then the sample cooked then rubbed, and finally shaken**

DIAMETER OF PARTICLES	METHOD 3. COOKED	METHODS 3 AND 2. COOKED, THEN RUBBED	METHODS 3, 2, AND 1. COOKED, RUBBED, SHAKEN
mm.	*per cent*	*per cent*	*per cent*
Under 0.02	54.1	53.8	54.3
0.05–0.02	30.4	30.4	30.8
0.1 –0.05	8.7	9.0	8.5
0.2 –0.1	2.8	3.1	3.1
2.0 –0.2	3.5	3.4	3.7
Total.....	99.5	99.7	100.4

* Data calculated from the registered sedimentation curves.

sample was cooked for 1 hour with a reflux condenser, as in method 3. For each treatment, the settling curves were made photographically. The data of table 2 are calculated from the dispersion curves.

The comparison of the finest fraction under 0.02 mm. shows that the same sample, which was shaken, was further dispersed by rubbing and that it acquired the highest dispersion by cooking.

Another sample of the same washed clay soil was so treated that it was cooked for 1 hour with a reflux condenser (method 3); then it was rubbed (method 2); and finally it was shaken for 6 hours (method 1). Thus the order of treatment was reversed. For every treatment the settling curve was made photographically. If the cooking was most effective, it must display the strongest action in the beginning; the subsequent treatments of rubbing and shaking should not increase the degree of dispersion. This is the case, as is shown in table 3.

TABLE 4

*The degree of dispersion of the same clay soil as used for data in tables 2 and 3. Washed, and the same sample rubbed, then shaken, and finally cooked**

DIAMETER OF PARTICLES	METHOD 2. RUBBED	METHODS 2 AND 1. RUBBED, THEN SHAKEN	METHODS 2, 1 AND 3. RUBBED, SHAKEN, COOKED
mm.	*per cent*	*per cent*	*per cent*
Under 0.02	53.1	53.0	56.1
0.05–0.02	31.2	32.0	29.3
0.1 –0.05	9.3	9.5	9.2
0.2 –0.1	3.5	3.1	2.9
2.0 –0.2	2.2	2.4	2.7
Total.....	99.0	100.0	100.2

* Data calculated from the registered sedimentation curves.

The cooking gave such an energetic dispersion of the washed soil, whose particles were completely charged above the critical potential, that the other treatments could exercise no further dispersing action.

Finally a third sample of the washed soil was rubbed (method 2), then the sample was shaken for 6 hours (method 1), and finally it was cooked for 1 hour with a reflux condenser (method 3). The maximum dispersion should occur with the last treatment, which was the case, as may be observed from table 4.

From these experiments, shaking as a method of preparation was more effective than cooking, for unwashed soil with higher electrolyte content and with potentials below the critical. In washed soils with low electrolyte content where the particle potential was greater than the critical, the dispersing action of cooking was more effective than that of rubbing and shaking. The action of a method of preparation is then largely dependent upon the electrolyte content of the soil and of the solution. The final effect may be contrary

for a single method, depending upon whether the soil particles are charged above or below the critical potential.

THE DEGREE OF DISPERSION OF A SOIL SUSPENSION PREPARED BY FREEZING[5]

Another physical influence which changes the degree of dispersion of a suspension is freezing. Although we scarcely apply it as a method of preparation for the mechanical soil analysis, freezing has, however, a practical significance for the estimation of the action of frost on soils. Further, the action of freezing is of theoretical interest. From the above it is to be expected that freezing would act for the most part in the same manner as an increase in the content of electrolytes; that is to say, coagulating, presupposing that enough electrolytes are present. With freezing, pure water separates, and the mother liquid is enriched in salts. The freezing should then cause flocculation in soils containing electrolytes. If, on the other hand, the electrolytes are carefully removed by washing, then the freezing should be without action, as no cause is given for the coagulation and as the particles charge themselves above the critical potential in the dispersing medium with a low content of electrolytes.

Experiments confirmed these predictions. The plan of experiment was as follows:

A soil sample of 100 gm., which had not been washed, was cooked with 600 cc. of water for ½ hour for the purpose of dispersing it; and then investigated in the Wiegner apparatus with the registering device of Gessner (method 1). After this, the same sample was frozen and the degree of dispersion measured again (method 2). The same sample was then washed with distilled water through an unglazed porcelain filter for 8 days, cooked for ½ hour and the degree of dispersion taken (method 3). Finally it was frozen again (method 4).

To the washed soil was added 0.001 *N* calcium chloride, and the curve for the dispersion taken (method 5). This sample containing the salt was finally frozen, and the degree of dispersion again registered (method 6).

A comparison of the data obtained with methods 1 and 2 should give the action of freezing on a soil which had not been washed; a comparison of data from methods 3 and 4, the action of freezing on the same but washed soil low in electrolyte content; a comparison of data from methods 5 and 6, the action of freezing on the same soil at a definite salt content (0.001 *N* $CaCl_2$). The data of table 5 show that the freezing had a coagulating action on the finer particles of the unwashed soil.

From table 6 the two dispersion curves of the same sample appear the same before and after the freezing of the washed soil, as was to be expected. The freezing had no influence on the degree of dispersion of the washed soil containing no electrolytes.

The effect of the addition of $CaCl_2$ is given in table 7. The soil has become coarser in degree of dispersion through the addition of $CaCl_2$ (com-

[5] Experiments by Aegidius Tschudi.

TABLE 5

*The influence of freezing on the dispersion of an unwashed Loess loam from Gönhard by Aarau**

One hundred grams cooked with 600 cc. of water. The degree of dispersion determined directly and after freezing.

DIAMETER OF PARTICLES	METHOD 1. DIRECT	METHOD 2. AFTER FREEZING
mm.	*per cent*	*per cent*
Under 0.02	40.0	27.5
0.05–0.02	40.0	50.0
0.1 –0.05	13.0	15.0
0.2 –0.1	5.0	4.5
2.0 –0.2	1.3	2.0
Total.....	99.3	99.0

* Data calculated from the registered sedimentation curves.

TABLE 6

*The influence of freezing on the degree of dispersion of a washed soil**

The same sample of Loess loam soil as used for the data of table 5. Washed 8 days with distilled water; the degree of dispersion determined directly and after freezing.

DIAMETER OF PARTICLES	METHOD 3. AFTER WASHING DIRECTLY	METHOD 4. AFTER WASHING AND FREEZING
mm.	*per cent*	*per cent*
Under 0.02	50.0	50.0
0.05–0.02	30.4	30.4
0.1 –0.05	13.0	13.0
0.2 –0.1	5.0	5.0
2.0 –0.2	1.3	1.3
Total.....	99.7	99.7

* Data calculated from the registered sedimentation curves.

TABLE 7

*The influence of freezing on the degree of dispersion of a salt-containing soil**

A Loess loam, washed for 8 days, then cooked, was treated with 0.001 *N* $CaCl_2$ and the degree of dispersion measured before and after freezing.

DIAMETER OF PARTICLES	METHOD 5. WASHED SOIL IN 0.001 *N* $CaCl_2$	METHOD 6. WASHED SOIL IN 0.001 *N* $CaCl_2$ AFTER FREEZING
mm.	*per cent*	*per cent*
Under 0.02	30.5	0.0
0.05–0.02	57.3	71.0
0.1 –0.05	10.8	22.0
0.2 –0.1	1.9	6.1
2.0 –0.2	0.0	1.2
Total.....	100.5	100.3

* Data calculated from the registered sedimentation curves.

paring left hand columns in tables 6 and 7, or method 3 with method 5). The finer particles decreased about 20 per cent through the $CaCl_2$ addition. The freezing in the presence of small amounts of calcium salts was so strongly flocculating that particles under 0.02 mm. diameter were no longer present in the frozen lime-containing soil suspension. Also cooking the frozen soil for ½ hour did not bring back the original degree of dispersion, as special experiments showed. In practical agriculture, we attribute to the frost a favorable flocculating action on the soil. The investigations on the suspensions show that the presence of electrolytes is one of the preliminary conditions for favorable end effects.

On the basis of these investigations it follows that the mechanical and physical methods of preparation may act entirely differently in a soil suspension, depending upon the electrolyte content of the soil. This content is the result of the degree of soil washing. It was demonstrated for example; that, the cooking was dispersing on washed soil low in electrolyte content; conversely, it was coagulating upon unwashed soil high in electrolyte content. This action is dependent upon the critical potential of the particles. As another example, freezing was coagulating on unwashed suspensions high in electrolyte content; whereas, on the other hand, it had no detectable action on dispersions low in electrolytes.

It is extraordinarily difficult to determine a definite end point for the washing with distilled water. The longer the soil is washed, the further the finest clay portions of the suspensions are hydrolyzed. Hydrogen ions replace alkali and alkaline earth ions in the clay, upon which depend changes in the swelling and imbibition, which in turn influence the size of the particles. There is then a point where the critical potential of the clay particles will be exceeded. We should exceed it in case we do not desire to measure coarse secondary aggregates; but on the other side of the critical point, the washing is increasingly active in changing the degree of dispersion.

THE DEGREE OF DISPERSION OF CARBONATE-FREE AND HUMUS-FREE SOIL SUSPENSIONS (SOIL 1458) AND OF CARBONATE-CONTAINING AND HUMUS-CONTAINING SOIL SUSPENSIONS (SOIL 1459)[6]

The experimental plan

In order to investigate the action of chemical additions, as of ammonia, which cause the increase of potential and increase of dispersion, measurements were carried out on the degree of dispersion in carbonate-free and humus-free soil sample 1458, and carbonate-containing and humus-containing ample 1459.[6] Placed at our disposal by *Dr. Hissink* of Groningen. The carbonate-containing sample had, according to the report of Novak (5) from 7.6 to 9.3 per cent calcium carbonate. The following plan of investigation

[6] Experiments by R. M. Barnette.

was used: the carbonate-free and humus-free soil sample *A* 1458 was investigated—the same sample being used—first after being cooked with water, then after it was thoroughly washed, and finally treated with increasing amounts of ammonia for the purpose of dispersing the particles.

The carbonate-containing and humus-containing soil sample (1459) was investigated, first, after being cooked with water, then after it was thoroughly washed, in order to investigate the effect of the dissolution of $CaCO_3$ by water.

Another sample *B* of the lime-containing sample (1459) was investigated, first, after being cooked, and then with increasing amounts of ammonia for dispersing the particles.

Finally a third sample *C* of the lime-containing soil (1459) was treated in the cold with a quantity of dilute HCl equivalent to the amount of $CaCO_3$, then thoroughly washed and finally dispersed with increasing amounts of ammonia. Every operation was controlled by registering the dispersion curve photographically.

The preparation of the samples was as follows:

1. Sample A of the carbonate-free Dutch soil (1458).

a. Soil sample *A* (100 gm. in 200 cc. of water) was cooked for ¼ hour; after cooling, it was diluted with water, and the degree of dispersion measured directly in the Wiegner apparatus with Gessner's registering device (method 1).

b. The same sample *A* was washed for three weeks with distilled water through an unglazed porcelain filter (method 2). The test for lime was still positive.

2. Sample B of the carbonate-containing Dutch soil (1459).

a. Sample *B* of the carbonate-containing soil (100 gm. in 200 cc.) was cooked for ¼ hour; after being cooled, the suspension was diluted with water and investigated directly (method 1).

b. The same sample *B*, unwashed, was treated with ammonia until the final content was equivalent to 0.01 (method 5).

c. The same sample *B*, unwashed, was raised to an ammonia content of 0.1 normal (method 6).

d. The same soil sample *B*, unwashed, was raised to an ammonia content of 0.5 normal (method 7).

3. Sample C of the carbonate-containing Dutch soil (1459).

a. A 100-gm. sample *C* of the carbonate-containing Dutch soil was treated with dilute hydrochloric acid approximately equivalent to the amount of calcium carbonate present. The sample was then washed for 3 weeks through an unglazed porcelain filter. The test for lime was still positive.

b. The sample *C* was treated with ammonia to a 0.1 normal content (method 9).

c. The same sample *C* was raised to an ammonia content of 0.5 normal (method 10).

The degree of dispersion of a carbonate-free soil suspension prepared by washing and by the addition of ammonia to the washed soil

1. Sample A of the carbonate-free Dutch soil (1458).

a. Table 8 gives the data calculated from the sedimentation curves of the cooked, the washed, and the ammonia-treated soil.

The figures of the second and third columns show that the removal of electrolytes from the soil was strongly dispersing. The addition of ammonia was

coagulating on the finer part of the washed soil (the percentage of the particles under 4μ obtained by methods 3 and 4 is smaller than from method 2); while ammonia was dispersing, if we choose the dispersion curve of the unwashed soil as a basis of comparison (the fraction under 4μ for methods 3 and 4, is greater than for method 1). We have here again the result that the influence of a method of preparation (in this case, the addition of ammonia) is different depending upon the electrolyte content of the sample. Ammonia was dispersing as long as the particles were under the critical potential.

TABLE 8

The influence of washing and the addition of ammonia on the degree of dispersion of a cooked carbonate-free Dutch soil (Sample A 1458)*

DIAMETER OF PARTICLES	METHOD 1. SAMPLE *A* COOKED	METHOD 2. SAME SAMPLE WASHED FOR 3 WEEKS	METHOD 3. SAME WASHED SAMPLE IN 0.1 *N* AMMONIA	METHOD 4. SAME WASHED SAMPLE IN 0.5 *N* AMMONIA
mm.	*per cent*	*per cent*	*per cent*	*per cent*
Under 0.004	42.89	69.70	61.42	59.46
0.006–0.004	17.40	5.15	14.28	15.75
0.008–0.006	7.53	2.73	2.28	2.53
0.010–0.008	3.24	3.03	2.00	2.85
0.012–0.010	2.85	1.82	5.14	2.57
0.014–0.012	4.67	3.03		2.85
0.016–0.014	2.86		4.28	1.43
0.018–0.016	2.59	1.21	2.57	2.57
0.020–0.018		0.60		2.28
0.030–0.020	5.97	9.04	2.86	3.14
0.040–0.030	6.25	1.05	2.86	3.14
0.050–0.040	1.25	1.05	2.31	1.43
Over 0.050	2.50	1.59	.....	.....
Total.....	100.00	100.00	100.00	100.00

* Data calculated from the registered sedimentation curves.

The degree of dispersion of a carbonate-containing soil suspension, prepared by washing, by the addition of ammonia to the unwashed soil, and by the addition of hydrochloric acid followed by treatment with ammonia

1. Sample A of the carbonate-containing Dutch soil (1459).

Table 9 shows the effect of the 3 weeks washing on the degree of dispersion of a soil containing carbonates. The washing of this carbonate-containing soil was strongly dispersing, as the percentage of the fine fractions shows.

2. Sample B of the carbonate-containing soil (1459).

The sample *B* of the carbonate-containing soil was cooked in water, then treated with ammonia to a content of 0.01 normal, 0.1 normal, and 0.5 normal. The results are given in table 10.

The addition of 0.01 normal and 0.1 normal ammonia has been clearly dispersing on the unwashed carbonate-containing soil; as in the case of the car-

bonate-free soil, the degree of dispersion of the finest fraction decreases in a comparison of the 0.1 normal treatment with the 0.5 normal ammonia. The long continued washing of the carbonate-containing soil appears to have been more active than the addition of ammonia (compare table 9—method 2, with table 10—methods 5, 6, and 7).

That the mere $\frac{1}{4}$ hour cooking is not sufficient to give a uniform homogenous reproducible dispersion in a carbonate-containing soil, is shown by a comparison of sample *A*, table 9, with sample *B*, table 10, treated by the same method

TABLE 9

The influence of washing (for 3 weeks through an unglazed porcelain filter) on the degree of dispersion of the cooked, carbonate-containing Dutch soil 1459*

DIAMETER OF PARTICLES	METHOD 1. SOIL SAMPLE *A*, COOKED	METHOD 2. SAME SAMPLE, WASHED FOR 3 WEEKS
mm.	*per cent*	*per cent*
Under 0.004	17.86	43.17
0.006–0.004	2.38	4.14
0.008–0.006	14.28	
0.010–0.008	1.90	2.00
0.012–0.010	2.38	2.19
0.014–0.012	2.86	2.44
0.016–0.014	2.38	2.00
0.018–0.016	1.90	1.71
0.020–0.018	3.57	0.20
0.030–0.020	7.35	14.10
0.040–0.030	6.50	4.39
0.050–0.040	2.73	2.19
0.060–0.050	3.66	2.44
0.070–0.060	2.20	1.14
0.080–0.070	1.70	1.30
0.100–0.080	2.44	1.46
0.140–0.100	2.20	1.71
0.200–0.140	2.20	2.19
2.000–0.200	19.51	11.46
Total.....	100.00	100.23

* Data calculated from the registered sedimentation curves.

1. Sample *A* is more finely divided than sample *B*. Both samples were coagulated by the cooking. Such a coagulation is dependent on a large number of factors which are extraordinarily hard to keep constant. An advantage of the Wiegner apparatus is that, in the study of the changes of a sample, we are independent of the condition at the beginning, as we study the same sample in its changes. Small differences between samples of the same soil cannot be controlled.

3. Sample C of the carbonate-containing Dutch soil (1459).

Sample *C* was freed from $CaCO_3$ with dilute hydrochloric acid in slight

excess. The dissolved substances were removed as fast as possible by washing for 3 weeks through an unglazed porcelain filter. The degree of dispersion was then measured and the further dispersion by 0.1 normal and 0.5 normal ammonia investigated. The results are given in table 11, in which the percentages are based on the carbonate-free soil.

The data show that the treatment with dilute hydrochloric acid and the washing out of the electrolytes gave a somewhat finer dispersion than the

TABLE 10

The influence of the addition of increasing amounts of ammonia on the degree of dispersion of the cooked, carbonate-containing, unwashed Dutch soil (Sample B 1459)*

DIAMETER OF PARTICLES	METHOD 1. SAMPLE *B* COOKED	METHOD 5. SAMPLE *B* IN 0.01 *N* NH_3	METHOD 6. SAMPLE *B* IN 0.1 *N* NH_3	METHOD 7. SAMPLE *B* IN 0.5 *N* NH_3
mm.	*per cent*	*per cent*	*per cent*	*per cent*
Under 0.004		21.42	26.92	9.76
0.006–0.004		3.33	5.71	27.50
0.008–0.006		4.76	3.57	3.50
0.010–0.008		2.14	2.38	3.00
0.012–0.010	33.33	2.86	2.38	3.00
0.014–0.012		2.38	2.14	1.75
0.016–0.014		2.14	2.62	3.50
0.018–0.016		2.14	2.62	2.50
0.020–0.018		2.38	2.14	1.38
0.030–0.020	18.33	6.19	5.17	6.10
0.040–0.030	5.47	4.66	5.20	5.13
0.050–0.040	4.47	5.36	4.02	3.86
0.060–0.050	2.90	6.58	4.76	3.57
0.070–0.060	3.09	1.95	2.14	2.14
0.080–0.070	2.38	2.44	2.38	2.38
0.100–0.080	2.38	2.19	3.57	2.62
0.140–0.100	2.38	2.44	2.38	2.38
0.200–0.140	2.14	2.92	2.86	2.38
2.000–0.200	22.60	21.46	16.66	13.81
Total.....	99.47	99.74	99.62	100.26

* Data calculated from the registered sedimentation curves.

direct treatment with ammonia (compare table 11—method 8, with table 10—methods 5, 6, and 7). The direct washing of the carbonate-containing sample with distilled water acted somewhat more strongly than the acid treatment alone (compare table 11—method 8, with table 9—method 2). The subsequent treatment of the acid extracted sample in 0.1 normal and 0.5 normal ammonia dispersed the soil further than it was possible to reach with any other sample.

Results of the Investigations

The results of the investigations are summarized as follows:

1. The action of the preparation of a soil suspension by *shaking*, by *rubbing*, or by *cooking* for the determination of the degree of dispersion is different, depending upon the electrolyte content of the suspension. The cooking of the soil sample is more strongly dispersing in comparison with the other two procedures, if the soil suspension is thoroughly washed and has only a very small content of electrolytes. The particles are then all charged above

TABLE 11

*The degree of dispersion of sample C of the carbonate-containing Dutch soil (1459) treated with dilute HCl for the decomposition of the carbonate, washed and suspended in water, then in in 0.1 N and finally 0.5 N ammonia**

DIAMETER OF PARTICLES	METHOD 8. SAMPLE *C* TREATED WITH HCl AND WASHED	METHOD 9. SAMPLE *C* IN 0.1 *N* NH_3	METHOD 10. SAMPLE *C* IN 0.5 *N* NH_3
mm.	*per cent*	*per cent*	*per cent*
Under 0.004	34.28	47.57	46.66
0.006–0.004	15.71	10.81	16.00
0.008–0.006	5.72	3.24	7.00
0.010–0.008	2.28	5.00	2.73
0.012–0.010	2.86	2.17	2.00
0.014–0.012	2.28	3.24	2.12
0.016–0.014	2.00		2.42
0.018–0.016	2.28	6.00	2.73
0.020–0.018	2.30		2.93
0.030–0.020	5.21	3.86	4.32
0.040–0.030	2.71	6.73	3.02
0.050–0.040	4.73	2.24	6.24
0.060–0.050	2.00	2.22	1.60
0.070–0.060		1.40	.....
0.080–0.070	1.32	.....	.....
0.100–0.080			
0.140–0.100	2.00	.....	.....
0.200–0.140	2.10	.....	.....
2.000–0.200	10.00	4.17	.....
Total.....	99.78	98.64	99.77

* Data calculated from the registered sedimentation curves.

the critical potential. On the other hand, with a definite electrolyte content, as is present in soil suspensions not washed carefully, the cooking often is more strongly coagulating than the other treatments.

2. The *freezing* of a soil suspension is coagulating on the dispersion if electrolytes are present, as is the case in unwashed soils. If the soil suspensions are thoroughly washed with distilled water, the freezing has no detectable influence on the degree of dispersion of the suspension. The frost action therefore differs according to the electrolyte content of the suspension.

3. The *addition of ammonia*, up to an optimum 0.1 normal concentration, is dispersing on carbonate-free and carbonate-containing soil suspensions which have not been especially

well washed. The washing out of the electrolytes with distilled water in both cases investigated is more strongly dispersing than the direct addition of ammonia to unwashed samples.

Lime-containing and humus-containing samples gave difficultly reproducible results for different samples in the preparation by cooking for ¼ hour. Ammonia dispersed these samples further. The most active method for increasing the degree of dispersion was the solution of the carbonate with dilute hydrochloric acid in the cold, a subsequent thorough washing through a filter, and finally the addition of a 0.1 to 0.5 normal ammonia solution.

4. In these investigations, *the apparatus of G. Wiegner with the photographical registering device of H. Gessner*, showed itself suitable for the study of minute changes in the degree of dispersion of one and the same soil sample.[7]

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[7] The investigations will be continued. The author at this time heartily thanks his co-workers, Dr. R. Gallay, Dr. Aegidius Tschudi, and Dr. R. M. Barnette for their skillful coöperation.

FURTHER STUDIES ON MICHIGAN SOIL PROFILES WITH SPECIAL REFERENCE TO DISPERSED MATERIALS

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It has been considered advisable to obtain additional information on the physico-chemical properties of the finer materials that are present in the different horizons of the Michigan soil profiles. Accordingly samples have been taken from the majority of the profiles of the major soil types of the southern and northern groups and brought to the laboratory, where certain studies have been made on them.

The rate of removal of the fine material upon extraction or dispersion with distilled water has been determined as well as the heat of wetting and nitrogen content of the materials dispersed. Furthermore, the amount of colloids present in the various horizons has been estimated by the heat of wetting method. Additional studies are in progress.

RATE OF DISPERSION

The Ontonagon soil profile was selected for use in the study of the rate of dispersion with distilled water and of the differences in the various properties of the different sized particles that remained in suspension over a 24-hour period. About two-pound samples from the A_1, A_2, and B_1 horizons were placed in 2-gallon jars. The dispersion of the fine materials was brought about by filling the jars with distilled water. The contents were vigorously agitated by means of a suction pump constructed of gas pipe and rubber stoppers. Twenty-four hours after agitation, the liquid and suspended materials were siphoned off and run through the Sharpless Super-centrifuge. The same speed of centrifuging was maintained throughout these tests. The liquid was first passed into the bowl through the largest opening and the residue remaining on the celluloid core in the bowl was separated into two portions; namely, the material at the base, designated as no. 1, and that above which formed a much thinner layer, designated as no. 2. The liquid was then passed into the bowl through the medium sized tube and the residue collected and added to the samples of no. 2. Following this treatment the liquid was again run into the bowl through the smallest tube of the separator and the mass collected, designated as no. 3. These processes were repeated twenty-four times, but inasmuch as the solids collected on the last centrifuging were so small in amount, they were grouped as shown in table 1.

It is to be noted from the data presented in table 1 that horizons A_2 and B_1 released more material on the first dispersion than they did in subsequent ones. As a matter of fact, about as much material was dispersed in the first treatment as there was in the remainder. On the other hand a sample collected from A_1 horizon gave up a very small amount of material the first time it was treated with distilled water and under these conditions it would not reach its maximum amount until the third treatment. Similar results have been observed with numerous soil horizons. This may be due to the presence of certain floccu-

TABLE 1

The rate of dispersion of fine material from Ontonagon profile

DISPERSIONS	A_1 HORIZON			A_2 HORIZON			B_1 HORIZON		
	1	2	3	1	2	3	1	2	3
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1	7.5	1		385	50		330	122	
2	26.0	3	6	48	28	4	57	21	13
3	391.0	17		71	10		62	20	
4	100.0	29	3	42	6	1	42	6	2
5	45.0	14		9	4		6	6	
6	100.0	14	3	30	4	1	19	3	1
7	108.0	18		25	9		25	5	
8	.....	7	2	18	4	1	19	5	1
9	60.0	17		20	7		23	11	
10	37.0	8	1	14	3	1	14	3	1
11	18.0	5		13	3		12	4	
12	25.0	5		9	2		9	3	
13	38.0	10		5	2		11	5	
14	32.0	7		8	2		10	3	
15	23.0	5		9	3		10	4	
16	20.0	5		5	2		12	7	
17	15.0	5		5	1		7	4	
18	13.0	3		5	1		7	4	
19	11.0	2		4	1		.....	.....	
20	11.0	3		3	1		6	3	
21	14.0	3		3	1		5	3	
22	15.0	3		4	1		4	2	
23	9.0	.....		1	1		5	2	

lating substances in the soil which are washed out by the large quantities of distilled water added to the soil.

HEAT OF WETTING

The heat of wetting determinations were made on the various groups of material as well as on that collected from the third dispersion of A_1 horizon and the first dispersion of A_2 and B_1 horizons respectively. The data obtained are given in table 2.

It is clear from these data that the materials that remain in suspension over a 24-hour period vary very widely in their properties; the finer materials, collected at the upper portion of the tube have an appreciably greater heat of wetting those at the base. It is of interest to note here that the materials with the lowest heat of wetting, when redispersed in a large volume of distilled water remained in suspension many days. It is probable that not only the size of the particles or the groups of them but also their specific gravities govern the position that they take in the tube. Several determinations of the specific gravities of some of the materials collected were made with a special type of pycnometer. This type has a bulb at the base and a stem about 10 cm. long with an enlarged upper end into which a ground glass stopper fits. Ligroin was used instead of water in the determinations because the fine materials would not disperse in it, and because there is probably less reactivity between this material and the soil

TABLE 2

Heat developed by each gram of material from Ontonagon soil horizons

	3RD DISPERSION	1ST TO 11TH DISPERSION	6TH TO 11TH DISPERSIONS	12TH TO 23RD DISPERSION
	calories	*calories*	*calories*	*calories*
A_1 no. 1.....	5.36		4.96	5.56
A_1 no. 2.....	9.36		8.21	8.44
A_1 no. 3.....		10.67		
A_2 no. 1.....	4.94		4.88	5.24
A_2 no. 2.....	9.00		7.99	7.60
A_2 no. 3.....		11.73		
B_1 no. 1.....	5.14		5.77	5.98
B_1 no. 2.....	9.53		8.69	8.42
B_1 no. 3.....		11.08		

particles than there is between water and them. The specific gravity of Ontonagon A_1 no. 1 was 2.638; A_1 no. 2, 2.564; B_1 no. 1, 2.795; and B_1 no. 2, 2.761.

Early in the investigations remarkable differences were observed in the color and tenacity of the materials that collected at or near the base of the centrifuge tube and those higher up. Usually the materials at the base proved to be easily pulverized when dry and the remainder much more tenacious and horny-like in nature. The heat of wetting of the former was much lower than that of the latter.

NITROGEN CONTENT OF DISPERSED MATERIALS

The nitrogen content of the above collected solids was determined. It is to be noted from the data in table 3 that the solids obtained by several dispersions were combined in order to obtain a sufficient amount of material for the determinations.

According to the results obtained by the authors there is a tendency for the nitrogen content of the particles obtained from the early and late dispersions, respectively, to be greater than it is of those from the intermediate ones taken from horizons A_1 and A_2, except specimens A_2 no. 2. Other points of interest are; more nitrogen in the materials collected from horizon A_1 no. 1, 2, and 3 than in A_2, no. 1, 2, and 3; and the relatively low amounts of nitrogen in the B_1 samples.

TABLE 3

The nitrogen content of dispersed materials from Ontonagon horizons

HORIZON	DISPERSION	NITROGEN CONTENT
		per cent
A_1 no. 1	3rd	0.28
A_1 no. 1	6th to 11th	0.22
A_1 no. 1	12th to 24th	0.31
A_1 no. 2	3rd	0.29
A_1 no. 2	6th to 11th	0.26
A_1 no. 2	12th to 24th	0.35
A_1 no. 3	1st to 11th	0.32
A_2 no. 1	1st	0.10
A_2 no. 1	6th to 11th	0.09
A_2 no. 1	12th to 24th	0.21
A_2 no. 2	1st	0.14
A_2 no. 2	6th to 11th	0.18
A_2 no. 2	12th to 24th	0.18
A_2 no. 3	1st to 11th	0.22
B_1 no. 1	1st	0.02
B_1 no. 1	6th to 11th	0.05
B_1 no. 1	12th to 24th	0.06
B_1 no. 2	1st	0.06
B_1 no. 2	6th to 11th	0.09
B_1 no. 2	12th to 24th	0.06
B_1 no. 3	1st to 11th	0.07

STUDIES ON MATERIALS COLLECTED BY EVAPORATION

Fine materials were collected from the different horizons of several soil profiles by dispersing them in distilled water. Four hundred grams of the soil were placed in a liter beaker. The beaker was filled with distilled water and the fine material dispersed by agitating with a stirring rod. After 24 hours the liquid was siphoned off and evaporated in an oven. The material was dispersed ten times and each time the liquid was drawn off and added to the dry residue in the evaporator. If after ten dispersions the required amount of fine material had not yet been obtained, a second 400 gm. was taken and the process repeated. In some cases this had to be done several times.

Heat of wetting

The heat of wetting determinations were made on these materials as well as on the original soil, and, on the assumption that the heat of wetting is all due

TABLE 4

Heat of wetting of soils and dispersed materials

SOIL TYPE	HORIZON	AMOUNT OF HEAT FROM EACH GRAM OF MATERIAL		COLLOIDS IN SOIL
		Soil	Colloids	
		calories	*calories*	*per cent*
Fox sandy loam	A	1.32	6.53	20.21
	B_1	2.50	9.04	27.65
	B_2	1.82	8.84	20.58
Hillsdale heavy sandy loam	A	0.93	5.91	15.73
	B_1	1.19	6.39	18.70
	B_2	1.24	6.07	10.42
Napanee silt loam	A	1.96	5.35	35.51
	B	2.93	7.13	41.09
	C	1.99	3.92	50.76
Kewanee loam	A	1.38	6.22	22.18
	B		7.33	
	C	1.72	4.61	37.31
Brookston silt loam	A	....	7.98	.....
	B	....	8.53	.....
	C	....	5.53	.....
Strong light sandy loam	A_1	0.42	8.70	5.18
	B_1	2.53	10.94	23.12
	B_2	1.11	9.97	11.13
Chippewa light sandy loam	A_1	0.72		
	B_1	2.66	19.93	13.34
	B_2	1.66	14.37	11.55
Onaway loam	A_1	0.49	4.20	11.66
	A_2	1.02	4.85	21.03
	B_1	2.41	6.68	36.07
Stalwart light sandy loam	A_1	1.12	4.98	22.49
	A_2	2.19	8.55	25.61
	B_1	1.62	7.71	21.01
Ontonagon silt loam	A_1	2.96	4.88	60.65
	A_2	3.21	5.57	57.63
	B_1	4.63	6.61	70.04

TABLE 5

Nitrogen in soils and fine materials

SOIL TYPE	HORIZON	NITROGEN IN SOIL	NITROGEN IN FINE MATERIAL
		per cent	*per cent*
Fox	A	0.081	0.16
	B	0.048	0.09
	B_2	0.036	0.08
Hillsdale	A	0.039	0.16
	B_1	0.010	0.10
	B_2	0.048	0.14
Napanee	A	0.112	0.30
	B	0.084	0.12
	C	0.070	0.09
Kewanee	A	0.050	0.16
	B	0	0.03
	C	0.045	0.07
Miami	A	0.224	0.38
	B	0.092	0.17
	D	0.070	0.10
Brookston	A	0.112	0.30
	B	0.110	0.25
	C	0.030	0.10
Strongs	A_1	0.106	0.95
	B_1	0.143	1.21
	B_2	0.098	1.00
Chippewa	A_1	0.062	1.04
	B_1	0.092	1.12
	B_2	0.143	1.24
Onaway	A_1	0.095	0.24
	A_2	0.050	0.19
	B_1	0.059	0.21
	C	0.035	0.06
Stalwart	A_1	0.070	0.28
	A_2	0.087	0.20
	B_1	0.062	0.16
Ontonagon	A_1	0.148	0.29
	A_2	0.081	0.13
	B_1	0.050	0.07

to the colloids and that the particles so extracted are representative of the mass, the percentage of colloids in the soil was estimated by the use of the formula

$$\frac{\text{Heat of Wetting of Soil}}{\text{Heat of Wetting of Colloids}} \times 100.$$

These results are given in table 4.

The heat of wetting values in table 4 are interesting in that the materials extracted from the northern Michigan soils, Strong and Chippewa, are remarkably active; especially is this true of the B horizons. The B horizons of the southern Michigan soils are also very active as measured by the heat evolved when they are brought into contact with water. As judged by the touch method, the amounts of colloids present in the Stalwart and Chippewa horizons are surprisingly high, otherwise the results are about as one would predict and similar to those previously reported.

Nitrogen content

The nitrogen content of the original samples and of the extracted materials has been determined and is shown in table 5. The results obtained from the studies on the various horizons are similar to those previously reported (10, 11). Notably, the coarser textured, strongly podsolized northern types or Strong, Chippewa, and Stalwart have high percentage of nitrogen in the B layers, whereas the finer textured ones, or the Ontonagon and Onaway as sampled, carry more of the element in the A horizon, the exception being A_1 of the latter type. The nitrogen content of the fine materials extracted from the northern soils, Chippewa and Strong, is strikingly high and the indications are that the majority of it in these types exists in the colloidal state. The probabilities are that the colloids for the most part are in the sol state.

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FACTORS AFFECTING THE HYDROGEN-ION CONCENTRATION OF SOILS[1]

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The hydrogen-ion concentration is perhaps the easiest and quickest method of studying the reaction of soils. It is used extensively as an expression of the acidity or alkalinity of a soil. The determination of the hydrogen-ion concentration in the laboratory and the use of the values thus obtained as expressions of the acidity in the field, however, involve the consideration of several factors: In the first place, does the hydrogen-ion concentration of a soil that has been prepared for the usual laboratory analyses give a true expression of the acidity of the soil in the field? Secondly, is the reaction of the soil in the field constant or variable?

It is the purpose of this paper to report certain studies which have been made of the factors that might influence the hydrogen-ion concentration of soils. Consideration was given to the effect of air-drying and grinding a soil on its reaction; to the periodical variations in the hydrogen-ion concentration of soils; to the effect of fertilizer treatments on soil acidity; and to the effect of surface treatment on the reaction of the subsurface layers. The results were obtained by the use of the quinhydrone electrode (4).

EXPERIMENTAL

Most of the experimental work in this study was carried out with the Wooster silt loam, which is the typical soil at the main station farm. It is a glacial sandstone and shale soil, acid throughout its entire profile. The surface and subsurface soil is a brown silt loam. Below 14 inches, the subsoil is a yellowish brown, light, silty clay loam. A further description of this soil together with its reaction profile is shown in figure 1.

The effect of air-drying a soil

Air-drying a soil often produces a change in its hydrogen-ion concentration. It is questionable, however, if the change that is brought about by air-drying

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is significant enough to warrant the conclusion that only fresh, moist samples should be used for determining the hydrogen-ion concentration of soils. Burgess (10) found that air-drying acid soils had little or no effect upon the pH values but that drying alkaline soils caused them to become somewhat less alkaline. With the latter he observed a decrease in alkalinity of 0.4 pH. Rost and Fieger (28) report a tendency toward increased acidity upon air-drying both acid and alkaline soils. Some became slightly more acid, others

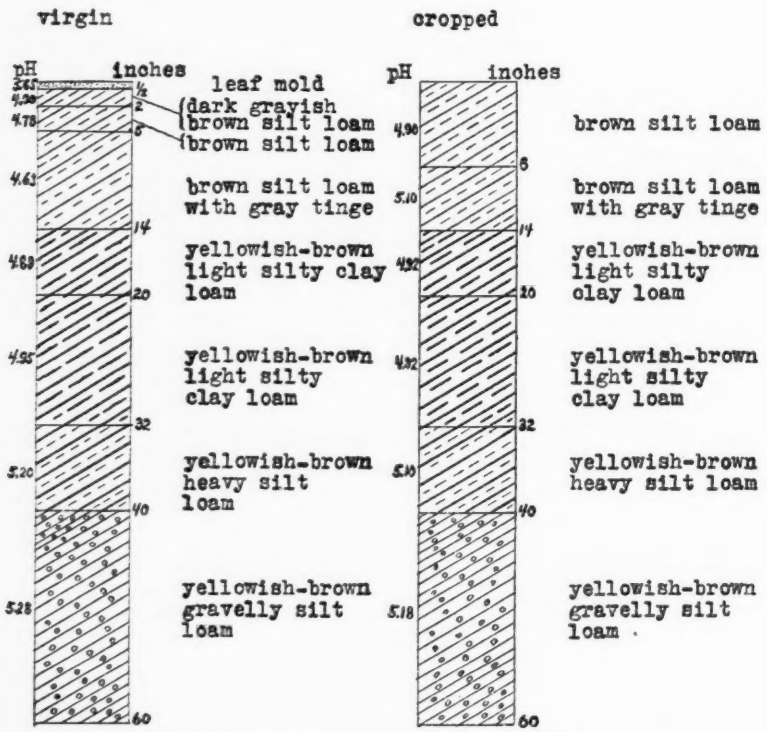

FIG. 1. DESCRIPTION AND REACTION PROFILE OF WOOSTER SILT LOAM

slightly less acid. They conclude that the only reliable indication of conditions existing in the field is obtained by using fresh samples for making hydrogen-ion determinations. Gardner and Brown (16) could not find a uniform effect of air-drying upon the lime requirement of a soil as determined by the Veitch method.

The results obtained in the present study shown in table 1 indicate that air-drying an acid soil does not significantly affect its reaction. However, there is a considerable decrease in alkalinity with the alkaline soils. With the sub-

soils, air-drying has caused a marked increase in acidity, which increases with depth. The amount of lime applied to the soil seems to have some influence on the change in reaction. Sample L-2 receives 2 tons of ground limestone to the acre; L-12, 4 tons; and L-20, 8 tons to the acre. There is a decrease in alkalinity upon air-drying these soils of 0.32, 0.23, and 0.01 pH, respectively. Samples L-12 and L-20 had practically the same reaction in the fresh condition. Thus, it would appear that the lime content of the soil might have some effect on the changes in the hydrogen-ion concentration of the soil as brought about by air-drying.

It is evident from the data in table 1 that the use of fresh samples for hydrogen-ion determinations gives a closer expression of the reacton of the soil as it occurs in the field than do the air-dried samples. With the acid surface soils, however, there was no appreciable change in reaction. It seems, therefore, that for practical purposes the hydrogen-ion concentration of an air-dried soil would give a sufficiently accurate expression of its reaction, but that fresh samples should be used for making refined reaction studies.

The effect of grinding

Grinding a soil may have a marked effect on its reaction. Brown and Johnson (8) found that grinding Iowa soils through an 80-mesh sieve considerably reduced their lime requirement, determined by the Veitch method, and frequently caused the reaction to become basic. Cook (13), on the other hand, observed that grinding sandy soils from New Jersey increased their acidity as determined by the Veitch method. Cook attributes the difference in the results of Brown and Johnson to a difference in soil type. Table 2 shows the effect of grinding a soil through a 100-mesh sieve on its hydrogen-ion concentration. Grinding the acid samples of the Wooster silt loam did not materially affect their reaction, but grinding the alkaline soils decreased their alkalinity. This was probably due to the exposing of surfaces that had not been affected by the additions of lime. The Brookston and Miami clays, glacial limestone soils, exhibit a decrease in acidity upon grinding. The Dunkirk fine sand, a glacial lake sand, shows a large decrease in acidity after it is ground.

This same effect was observed by Brown and Johnson (8) of Iowa. They attributed this reduction in acidity upon grinding to a solution of the minerals in the soil. Cook (13) concludes that perhaps the soils of Iowa are not "sands" in the purely chemical sense, but consist of particles having a basic internal constitution, the surface of which may have become acid on exposure. It appears that these reductions in acidity are probably due to the exposing of basic materials that are included in the soil particles. At any rate the results indicate that grinding a soil changes its reaction to such an extent that only unground samples should be used for making hydrogen-ion determinations.

TABLE 1

The hydrogen-ion concentration of the soil as influenced by air-drying

PLOT	DEPTH	MOIST SAMPLE	AIR-DRIED SAMPLE	CHANGE IN H-ION CONCENTRATION
	inches	*pH*	*pH*	*pH*
1-E*	0–7	5.02	4.94	−0.08
2-E	0–7	4.85	4.83	−0.02
3-E	0–7	4.81	4.75	−0.05
4-E	0–7	4.76	4.75	−0.01
5-E	0–7	4.85	4.76	−0.09
6-E	0–7	4.84	4.90	+0.06
7-E	0–7	4.75	4.70	−0.05
24-E	0–7	4.41	4.47	+0.06
11	0–7	4.85	4.89	+0.04
18	0–7	5.03	5.09	+0.06
22	0–7	5.06	5.00	−0.06
24	0–7	4.56	4.56	0.00
1-W	0–7	8.14	7.81	−0.32
2-W	0–7	7.68	7.50	−0.18
3-W	0–7	7.77	7.45	−0.32
4-W	0–7	7.77	7.45	−0.32
5-W	0–7	7.86	7.56	−0.30
6-W	0–7	7.72	7.43	−0.29
7-W	0–7	7.71	7.39	−0.32
8-W	0–7	7.71	7.33	−0.38
9-W	0–7	7.71	7.52	−0.19
10-W	0–7	7.77	7.60	−0.17
11-W	0–7	7.86	7.54	−0.32
12-W	0–7	7.76	7.64	−0.12
L-4	0–7	5.41	5.31	−0.10
L-4	7–14	5.60	5.12	−0.48
L-4	14–21	5.35	4.81	−0.54
L-4	21–28	5.32	4.69	−0.63
L-2	0–7	6.88	6.47	−0.41
L-2	7–14	5.54	5.22	−0.32
L-2	14–21	5.33	4.81	−0.52
L-2	21–28	5.29	4.79	−0.59
L-12	0–7	7.75	7.52	−0.23
L-12	7–14	6.25	5.86	−0.39
L-12	14–21	5.59	5.20	−0.39
L-12	21–28	5.49	4.95	−0.54
L-20	0–7	7.73	7.72	−0.01
L-20	7–14	6.59	6.23	−0.36
L-20	14–21	5.74	5.36	−0.38
L-20	21–28	5.51	5.10	−0.41

* Plots E and W are from the 5-year rotation, east and west ends.
Plots L are from the supplemental lime tests.

Periodical variations in reaction

The time of sampling appears to be a significant factor in studying the hydrogen-ion concentration of soils. Burd and Martin (9) found changes varying from 0.2 to 0.6 pH from April to September. Burgess (11) reports similar variations from May to September, the acidity being greater during July and August. Erdman (15) shows fluctuations of 0.35 pH from March until August. The acid soils exhibited greater acidity at the close of this period, but there was no consistency in the variation of the alkaline soils. Gardner and Brown (16) in periodically studying the lime requirement of fertility plots report variations from 0 to 1040 pounds to the acre from June 15

TABLE 2

The effect of grinding a soil on its reaction

SOIL		DEGREE OF FINENESS		CHANGE IN H-ION CONCENTRATION
Number	Type	2 mm.	100-mesh	
		pH	*pH*	*pH*
1-E	Wooster silt loam	4.94	4.96	+0.02
2-E		4.83	4.81	−0.02
3-E		4.75	4.90	+0.15
4-E		4.75	4.90	+0.15
5-E		4.76	4.76	0.00
1-W		7.81	7.56	−0.25
2-W		7.50	7.18	−0.32
3-W		7.45	7.12	−0.33
4-W		7.45	7.14	−0.31
5-W		7.56	7.27	−0.29
6-A	Brookston clay	6.24	6.46	+0.22
7-A	Miami clay	5.11	5.35	+0.24
85-A	Dunkirk fine sand	5.87	6.87	+1.00
88-A		5.55	6.84	+1.29

to August 15. The acid plots showed a higher lime requirement in August than in June. Kelley (20) observed changes of 1.0 pH during the entire year, with a continual increase in acidity from July to October. Kurz (21) noticed deviations of 1.0 pH during the year. Lipman and his associates (22) show fluctuations of 0.7 pH from May to November. Mather (24) reports variations of 0.7 pH from May to July with an increase in acidity in July.

In a preliminary study of the reaction of several of the 5-year rotation fertility plots, samples that were taken in the late summer or fall were found to be more acid than those taken in the spring (table 3). This led to a periodical study of the hydrogen-ion concentration of the soil. Four different samples were taken periodically during the growing season of 1925. Samples A and

TABLE 3

Periodical variation in the hydrogen-ion concentration of several fertility plots of Section D, 5-year rotation

PLOT	DATE OF SAMPLING					
	1894	1923 August 1	1924 April 17	1924 June 30	1925 April 21	1925 September 25
	pH	*pH*	*pH*	*pH*	*pH*	*pH*
2	....	....	5.05	4.75	4.97	4.83
3	5.07	....	5.04	4.64	4.93	4.75
5	....	....	5.14	4.55	4.91	4.76
11	4.88	....	5.06	4.65	4.85	4.74
18	4.96	5.04	5.24	4.68	5.03	4.92
22	4.90	4.98	5.08	4.80	5.06	4.88
24	4.97	4.73	4.90	4.39	4.56	4.47

TABLE 4

The relation of rainfall to variations in the hydrogen-ion concentration of the soil

DATE	RAINFALL		SAMPLE A	SAMPLE B	SAMPLE C	SAMPLE D
		inches	*pH*	*pH*	*pH*	*pH*
April 29	Before	0.47	7.10	5.83	....	....
May 2	After		7.22	5.61	....	....
May 2	Before	0.70	7.22	5.61	....	....
May 8	After		7.17	5.46	....	....
May 8	Before	0.73	7.17	5.46	....	....
May 11	After		6.80	5.52	....	....
May 15	Before	0.24	7.35	5.55	....	....
May 18	After		7.08	5.40	....	....
May 21	Before	0.65	7.05	5.65	....	....
May 26	After		7.08	5.40	....	....
July 13	After	2.65	6.98	5.33	6.10	4.92
July 17	Before	0.31	7.25	5.30	6.30	4.88
July 24	After		7.12	5.11	6.31	4.86
Sept. 16	After	2.49	7.15	5.04	6.52	4.71
Sept 21	Before	0.02	7.40	5.00	6.70	4.79
Sept. 23	After		7.33	5.04	6.57	4.81

B were sod plots having alkaline and acid reactions, respectively. Samples C and D were taken from cultivated plots. These were chosen to study the relation, if any, between cultivation and the periodic change in the soil reaction. At the time of sampling, a record was kept of the moisture content of the soil, the rainfall, the relative humidity, and the temperature in order to observe any correlation between these factors and the changes in the hydro-

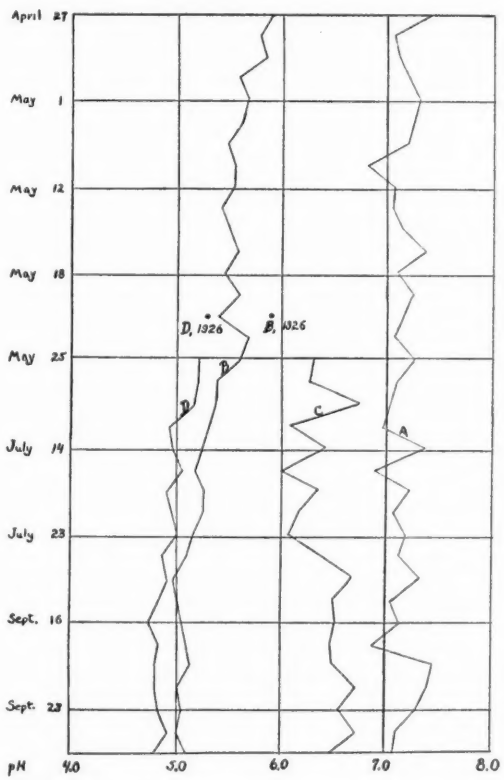

FIG. 2. VARIATIONS IN SOIL REACTION ON FOUR PLOTS FROM APRIL 27 TO SEPTEMBER 23

gen-ion concentration. All hydrogen-ion determinations were made on the air-dried samples.

The results in table 4 show variations in the pH values of samples A, B, C, and D of 0.60, 0.92, 0.71, and 0.54, respectively. The acid samples, B and D, exhibit a continual increase in their hydrogen-ion concentrations from May to September. These results are in close agreement with those reported by Burgess (11), Erdman (15), Gardner and Brown (16), Kelley (19), and Mather

(23), who observed an increase in acidity from the spring months to the late summer and fall. The alkaline plots show no consistent variations during this period. A graphic representation of the data shows these changes more clearly (fig. 2).

TABLE 5

Periodical variations in the reaction of a soil

DATE	SAMPLE A	SAMPLE B	SAMPLE C	SAMPLE D
	pH	*pH*	*pH*	*pH*
April 27, 1925	7.40	5.89	....	....
28	7.06	5.78	....	....
29	7.10	5.83	....	....
30	7.18	5.56	....	....
May 1	7.27	5.64	....	....
2	7.22	5.61	....	....
8	7.17	5.46	....	....
11	6.80	5.52	....	....
12	7.05	5.52	....	....
13	7.04	5.39	....	....
14	7.11	5.44	....	....
15	7.35	5.55	....	....
18	7.08	5.40	....	....
19	7.24	5.55	....	....
20	7.15	5.35	....	....
21	7.05	5.65	....	....
25	7.25	5.57	6.31	5.25
26	7.08	5.40	6.27	5.24
27	7.01	5.39	6.71	5.20
July 13	6.98	5.33	6.10	4.92
14	7.39	5.28	6.40	4.94
15	6.90	5.19	6.00	5.06
17	7.25	5.30	6.30	4.88
22	7.07	5.29	6.16	....
23	7.21	5.20	6.10	5.00
24	7.12	5.11	6.31	4.86
Sept. 14	7.36	4.97	6.63	4.90
15	7.02	5.00	6.50	4.80
16	7.15	5.04	6.52	4.71
17	6.83	5.10	6.47	4.82
18	7.46	5.11	6.50	4.80
21	7.40	5.00	6.70	4.79
23	7.33	5.04	6.57	4.81
24	7.12	5.00	6.71	4.90
29	7.10	5.09	6.45	4.77
May 20, 1926	....	5.85	....	5.25

There appears to be no definite correlation of moisture content, relative humidity, and temperature with the changes in the soil reaction. Rainfall seems to have some influence on the variations in the pH values (table 4). The acidity of the soil, observed before and after a precipitation of rain, in-

creased after the rain 12 times in 18 observations. Kelley (20) also observed an increase in the hydrogen-ion concentration following a rain.

The time of year appears to be an important factor, in the case of the acid soils especially. There is a consistent increase in acidity from the spring to the fall with a return to approximately the original acidity the next spring. Two probable explanations might be given for this phenomenon: First, it may be due to the dehydration of the hydrated colloidal silicates with a decrease in buffer action during the hot and dry summer months. The rainfall and moisture conditions of the winter and spring saturate the soil with water and the colloidal silicates resume the hydrated state, thereby causing the acidity to return to about the same value each spring. Or, in the second place, there may be an accumulation of salts in the soil during the summer which would tend toward increased acidity. During the winter and spring these salts would be leached away, producing a reduction in acidity. This recurrence of acidity was also observed by Kelley (20). It is shown in tables 3 and 5 and figure 2.

The foregoing results show the importance of the seasonal factor in studying the hydrogen-ion concentration of soils. Therefore, to say that a given soil has a definite pH value implies that there may be a variation of more than 0.2 in pH above or below the assigned value from time to time. The determination of the hydrogen-ion concentration of a field soil and its expression in terms of pH to the second decimal place scarcely seems logical if one considers these variations.

The effect of fertilizer treatment

There has been considerable discussion as to the effect of fertilizer treatments on the acidity of the soil. Most of the investigators, however, conclude that with the exception of ammonium sulfate the various fertilizers exert no appreciable influence on the reaction of the soil. Allison and Cook (1), Blair and Prince (6), Brioux (7), Crowther (14), Gardner and Brown (16), Lipman and his associates (23), Morse (25), Plummer (27), Stephenson (30), and Veitch (31) observed that ammonium sulfate increased the acidity of the soil. Sodium nitrate had a tendency to reduce it. Ames and Schollenberger (2), in studying the loss of calcium carbonate from the soil, could not find any consistent variations which could be attributed to soil treatment with the exception of the ammonium sulfate plot which showed a complete loss of the carbonate. Hall (17) reported the largest losses of calcium carbonate from the ammonium sulfate plot and the smallest from sodium nitrate in Broadbalk and Hoos Fields at Rothamsted. Morse (26) observed that twice as much calcium carbonate was leached away in the drainage waters from the ammonium sulfate treatment as from sodium nitrate.

In regard to acid phosphate, Skinner and Beattie (29) claim that it causes an increase in the acidity of the soil. On the other hand, Ames and Schollenberger (2), Brioux (7), Crowther (14), Karraker (19), Lipman and associates

(23), Morse (25), and Plummer (27) found no material effect of acid phosphate on soil acidity. Bauer and Haas (3), Bear and Salter (5), Conner (12), and Veitch (31) conclude that acid phosphate tends somewhat to reduce the acidity of the soil.

Manures do not materially affect the soil reaction as reported by Ames and Schollenberger (2), Howard (18), Karraker (19), and Stephenson (30). Crowther (14), however, observed a reduction of about 0.5 pH in the soil at Woburn with the use of barnyard manure.

TABLE 6

The effect of 30 years' fertilizing and cropping on the hydrogen-ion concentration of the Wooster silt loam

PLOT	SECTION D*			
	Treatment	East half† 1894	East half September 1925	West half‡ September 1925
		pH	*pH*	*pH*
2	P	....	4.83	7.50
3	K	5.07	4.75	7.45
4	None	5.14	4.75	7.45
5	N	....	4.76	7.56
11	N, P, K	4.88	4.74	7.54
18	Manure, 16 T	4.96	4.92	7.55
19	None	5.03	4.84	7.41
20	Manure 8 T.	5.16	4.86	7.60
24	N in $(NH_4)_2SO_4$	4.97	4.47	7.16
25	None	5.08	4.77	7.59
26	P in bonemeal	5.19	4.97	7.50
29	P in basic slag	5.19	4.93	7.68

* For a more complete outline of the fertilizer treatment of these plots, see Ohio Agr. Exp. Sta. Bul. 381.

† The time of the year when these samples were taken is not known.

‡ 32,654 pounds of calcium carbonate since 1894.

Erdman (15) observed that gypsum in excess of 1000 to 2000 pounds to the acre increased the acidity of the soil, but when added in smaller amounts it had practically no effect.

The 5-year rotation fertility plots at the Ohio Station afford an excellent opportunity for studying the effects of different fertilizer treatments on soil acidity. In this experiment corn, oats, wheat, clover, and timothy are grown in succession on five sections of land, containing 30 one-tenth acre plots each. The experiment was started in 1894. At this time the deficiency of the soil

in lime was not noticed, but the failing of the clover crops soon showed the necessity of liming. In 1900 the experiment of liming half of each plot was started. Since then the entire west half of section D has received ground limestone amounting to about 16 tons, applied to the corn. This has been added at the rate of about 2 tons to each acre. Table 6 gives the pH values of plots receiving standard fertilizer treatments, together with the hydrogen-ion concentration of some of the samples taken in 1894. A complete report of the reaction of all of the fertility plots will appear later.

The unfertilized plots have an average pH value of 4.76. It is evident from the results in table 6 that mineral manures, with the exception of ammonium sulfate, have caused no significant change in the reaction of this soil. The ammonium sulfate plot (plot 24) is the most acid, having a pH value of 4.47 at this time. The results indicate that acid phosphate, manure, bone-meal, and basic slag have a slight tendency to decrease the acidity. The application of lime has corrected the acidity in all cases. In most of the plots a slight alkalinity has developed. The use of lime for neutralizing the acids produced from ammonium sulfate is readily seen in plot 24 which after liming has a pH value of 7.16.

From the difference in the results observed in 1894 and 1925, it might be inferred that there has been considerable increase in acidity in some of the plots, but this conclusion cannot be safely drawn. In the first place, the 1894 samples were taken with a spade and perhaps are not very representative of the true reaction of the soil at that time. The large variation in a few of the samples tends to justify this statement. Secondly, the exact time of sampling in 1894 is not known. This is an important factor as previous results have shown. The results in table 3 show that the difference between the 1894 and 1925 samples are not as great as the seasonal variation. Thus, it appears that there has been no significant change in the reaction of the untreated plots during the last 30 years. Since it appears that agricultural practices, without the use of fertilizers and soil amendments, in the last three decades have not caused an increase in soil acidity, it seems that an equilibrium point in the hydrogen-ion concentration of the Wooster silt loam perhaps has been reached. In this case, the process of leaching and removal of bases from the soil has either reached a minimum or some other factor is maintaining the present hydrogen-ion concentration of the soil. Before any conclusions can be definitely established in regard to this question, further studies must be made. At this time, however, the fact must not be overlooked that 30 years is a short time when compared with the total length of time that the soil has been leaching.

The effect of surface treatment on the reaction of the subsurface layers

It is of interest to determine the extent to which a change of reaction in the surface layer affects the lower depths of the soil. A series of plots from the supplemental lime tests, which were started in 1911, were sampled at suc-

cessive depths of 7 inches down to 28 inches. These plots have received applications of ground limestone ranging from 0 to 8 tons to the acre, applied to the corn in a 4-year rotation of corn, oats, wheat, and clover. The hydrogen-ion concentrations of the different depths are reported in table 7. In addition to these results, the pH values of the surface and subsoil of the lime

TABLE 7

The effect of surface treatment on the reaction of the subsurface layers

PLOT*	LIME TREATMENTS		HYDROGEN-ION CONCENTRATION AT DIFFERENT DEPTHS			
	Kind of lime applied in pounds per acre	Total amount applied per plot in terms of $CaCO_3$	0 to 7 inches	7 to 14 inches	14 to 21 inches	21 to 28 inches
		pounds	*pH*	*pH*	*pH*	*pH*
L-4	None	None	5.31	5.12	4.81	4.69
L-2	4,000, ground limestone + manure	400	6.47	5.22	4.81	4.79
L-12	8,000, ground limestone + manure	800	7.52	5.86	5.20	4.95
L-20	16,000, ground limestone + manure	1,600	7.72	6.23	5.36	5.10
				7 to 20 inches		
LF-1	None	None	5.58	5.16		
LF-2	500, quicklime + manure	310	6.44	5.29		
LF-3	1,000, quicklime + manure	620	7.13	5.43		
LF-5	2,000, quicklime + manure	1,250	7.94	6.64		
LF-6	1,780, ground limestone + manure	620	7.05	5.71		
LF-7	None	None	5.58	5.43		
LF-8	1,780, air-slaked lime + manure	840	7.40	5.77		
LF-9	1,320, hydrated lime + manure	620	7.27	5.95		
LF-14	1,000, quicklime	620	7.12	5.74		
LF-15	1,780, limestone	620	6.59	5.52		
LF-16	None	None	5.36	5.31		
LF-17	1,000, quicklime + acid phos., KCl	620	7.00	5.45		
LF-18	1,000, quicklime + floats, KCl	620	7.03	5.53		

* Plots L from the supplemental lime tests.

Plots LF from the lime and floats test. For a complete description of the plots see Ohio Agr. Exp. Sta. Bul. 381.

plots from the lime and floats experiment are given. The total amount of lime, in terms of calcium carbonate, that each plot has received since the beginning of the experiment is recorded in the third column of the table. The effect of the surface treatment on the lower depths is shown more definitely in figure 3.

As these results clearly show, the 2 ton application of lime (plot L-2), has had little effect below 7 inches. With the 4 (plot L-12) and 8 (plot L-20) ton applications there has been a marked decrease in acidity in the second depth, with a gradual reduction in the hydrogen-ion concentration to 28 inches. The 8 ton addition has produced the largest reduction. In the lime

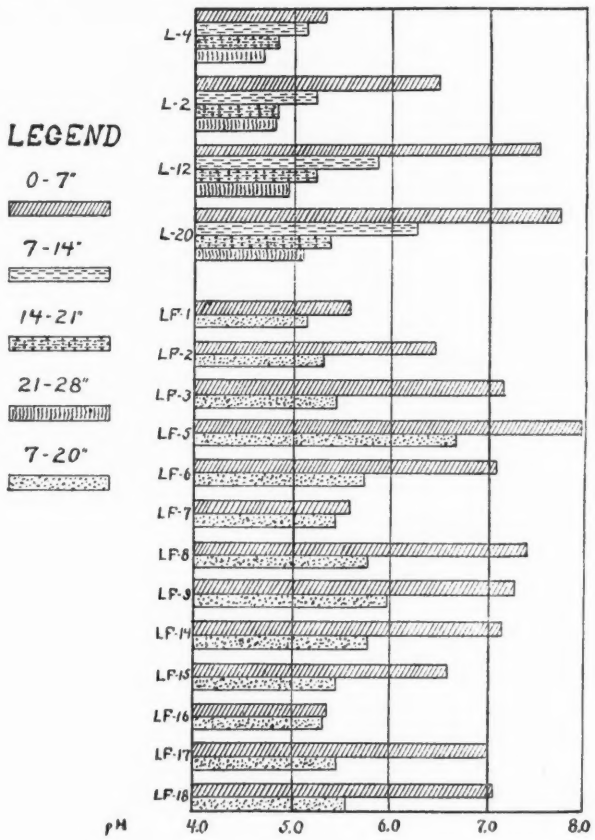

FIG. 3. EFFECT OF SURFACE TREATMENT ON SUBSURFACE LAYERS

and floats plots, the effect of lime is detected in all the subsoils with the exception of the 500 pound application of quicklime. Plot LF-5, with 2000 pounds of calcium oxide, has produced the largest reduction in the acidity of the subsurface layer.

It is logical to assume that the effect of the surface treatment on the lower depths will be more pronounced as the experiments progress. The buffer

action of soils and the relatively slow movement of the soil water are two of the determining factors in the rate of change in the reaction of the subsoil layers. The subsoil reaction, especially to a depth of 20 inches, should be a factor in determining the efficiency of liming. It is improbable that a calcium carbonate reserve in the soil will be maintained unless the acidity of the subsoil to at least 20 inches is corrected.

SUMMARY

In this paper are presented the results of an investigation of some of the probable factors that affect the hydrogen-ion concentration of soils.

The Wooster silt loam, the soil used in these investigations, is a glacial sandstone and shale soil having a decidedly acid reaction profile.

Air-drying the acid surface soil did not materially affect its hydrogen-ion concentration. The alkaline soils decreased in alkalinity.

Subsoil samples showed a large increase in acidity when they were air-dried.

The amount of lime in the soil appears to have some effect upon the changes in the reaction of a soil when air-dried.

Grinding acid samples of the Wooster silt loam did not appreciably change their reaction. Alkaline samples decreased in alkalinity, probably because of the exposing of surfaces that had not been affected by the additions of lime.

Grinding the Brookston and Miami clay and the Dunkirk fine sand decreased their acidity considerably. This decrease is probably due to the exposing of basic materials upon grinding.

The hydrogen-ion concentration of a soil varies throughout the year. Alkaline soils showed variations in acidity ranging from 0.6 to 0.7 pH from May to September.

Acid soils varied as much as 0.92 pH during this period. There was a continual increase in acidity from May to September, with the hydrogen-ion concentration returning to approximately the same value each spring. This phenomenon might be due to the dehydration of the hydrated colloidal silicates or to the accumulation of soluble salts during the summer months.

Rainfall and the season seem to be two important factors affecting these variations in the soil reaction.

Fertilizer treatments do not influence the hydrogen-ion concentration of soils to any considerable extent, with the exception of ammonium sulfate which causes an increase in acidity; although acid phosphate, sodium nitrate, bonemeal, basic slag, and manure tend somewhat to reduce it.

Applications of lime have corrected the acid nature of the soil, producing a slightly alkaline reaction.

There appears to have been no significant change in the hydrogen-ion concentration of the Wooster silt loam in the last 30 years.

From these results, the assumption is made that an equilibrium point may have been reached in the reaction of this soil, whereby, under ordinary conditions, the hydrogen-ion concentration will not show further change.

The surface treatment of a soil influences the reaction of the lower depths. Over a period of 11 years, 4 and 8 tons of ground limestone, added every 4 years in the rotation, have affected the reaction of the subsoil as deep as 28 inches. The effect of 2 tons per acre can be seen only in the surface layer.

The acidity of the subsoil of plot 5 of the lime and floats experiment, receiving 2000 pounds of calcium oxide to the acre every 3 years for 20 years, has been reduced almost to neutrality, having a pH of 6.64 at a depth of 20 inches.

CONCLUSIONS

A study of some of the factors that may affect the hydrogenion concentrations of soils leads to the following conclusions:

1. Fresh, moist samples should be used for making detailed reaction studies. Air-dried samples seem to give sufficiently accurate results for any ordinary purposes.
2. Hydrogen-ion concentration determinations should be made on unground soil samples. Grinding affects the reaction of a soil to such an extent that the results may be misleading.
3. The periodical variation in the pH values of soils should be considered in all hydrogen-ion concentration measurements. The expression of the reaction of a field soil in terms of pH to the second decimal place does not appear logical in view of the variability of the pH value.
4. The hydrogen-ion concentration of the soil is not materially affected by fertilizer treatments, with the exception of ammonium sulfate. The increase in acidity from the use of ammonium sulfate in ordinary amounts, however, is not significant enough to diminish its value as a commercial fertilizer.
5. The hydrogen-ion concentration of the subsoil is influenced by the treatment of the surface soil. The reaction of the subsurface layers should be a factor in determining the efficiency of liming. The removal of subsoil acidity to at least 20 inches is necessary to maintain a calcium carbonate reserve in the soil.

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BOOK REVIEWS

Anleitung zum quantitativen agrikulturchemischen Praktikum. (*Methods of analysis in agricultural chemistry.*) By Prof. G. WIEGNER with the collaboration of Dr. H. JENNY. Gebrüder Borntraeger, Berlin, 1926. Pp. 348, fig. 33.

The author of this book is the well known Professor of Soil Chemistry at the Agricultural Institute in Zürich, Switzerland. He presents here, concisely and clearly, all the information and directions which are essential in quantitative analysis and its application to agricultural chemistry, especially the quantitative methods of physical and chemical analysis of soils and fertilizers. The most recent methods have been treated in a most accurate and careful manner.

The book is divided into four parts: 1. Gravimetric and volumetric methods of analysis. 2. Investigation of artificial fertilizers. 3. Physical and chemical soil investigation. 4. Chemical investigation of foodstuffs. A table of atomic weights, a 4-place logarithmic table, and excellent name and subject indices are appended.

Although written as a laboratory text for students in agricultural chemistry, the book will prove a valuable addition to every chemical laboratory where soils, fertilizers, feeds, or milk products are analyzed. No one interested in the subject, either from the point of view of teaching, analysis, or research can afford to overlook this book.

The book is well printed and the different methods are properly illustrated and clearly defined.

S. A. WAKSMAN.

The composition and distribution of the protozoan fauna of the soil. By H. SANDON. Oliver and Boyd, Edinburgh and London, 1927. Pp. xiii + 227, pl. 6, charts 3.

Although the existence of protozoa in the soil has been known since the time of Ehrenberg and Greef, and the great abundance of these organisms in the soil, both in numbers and in species, has been pointed out by Wolff and others, it was only in 1909, with the work of Russell and Hutchinson on partial sterilization of soil, that a systematic study of the distribution of protozoa in the soil was begun. These investigators advanced the theory that the favorable effect of partial sterilization of soil upon the numbers and activities of bacteria and upon plant growth is due to the elimination of protozoa, which otherwise consume the bacterial population of the soil as food. The subsequent studies on the protozoa of the soil were greatly influenced by this theory, many investigators being concerned largely with obtaining information which would

support or refute it. Other investigators, however, were more concerned with gaining further information on the physiology of protozoa, their distribution in various soil types, and their activities in the soil as influenced by environmental conditions.

The author of this monograph, a member of the Rothamsted Station, England, succeeded in carrying out by far the most extensive study of the distribution of protozoa in different parts of the world, under various environmental conditions. As a result of his own investigations and also after a thorough study of the literature, the author recognized that "the time had come when the chapter of soil protozoology could be brought to a close by bringing together all the available records, reconciling wherever possible their mutual inconsistencies and contradictions, thus presenting for the use of the soil microbiologist and the general naturalist a clear and tolerably complete picture of this group of organisms and of their distribution in the soil." The object of the work reported in the monograph was to "pave the way for more detailed inquiries . . . . by giving a general review of protozoa occurring in the soil, and of the factors influencing their distribution."

The author dissociates completely the study of protozoa, a very extensive group of soil organisms which no doubt play an important rôle in the numerous soil processes, from the subject of partial sterilization of soil.

The major part of the monograph is devoted to a study of the distribution of protozoa in 148 soils collected from different parts of the world, including the polar regions and tropical regions, as well as an analysis of the factors influencing this distribution. A description of all the species so far authentically recorded from soils, and original observations concerning some new species then follow. Artificial keys are added to assist in the identification, except in the case of naked Rhizopoda, which do not lend themselves to this treatment.

The book is well printed and the six plates, some of which are original drawings of the various soil protozoa, are executed in a most excellent manner.

S. A. WAKSMAN.